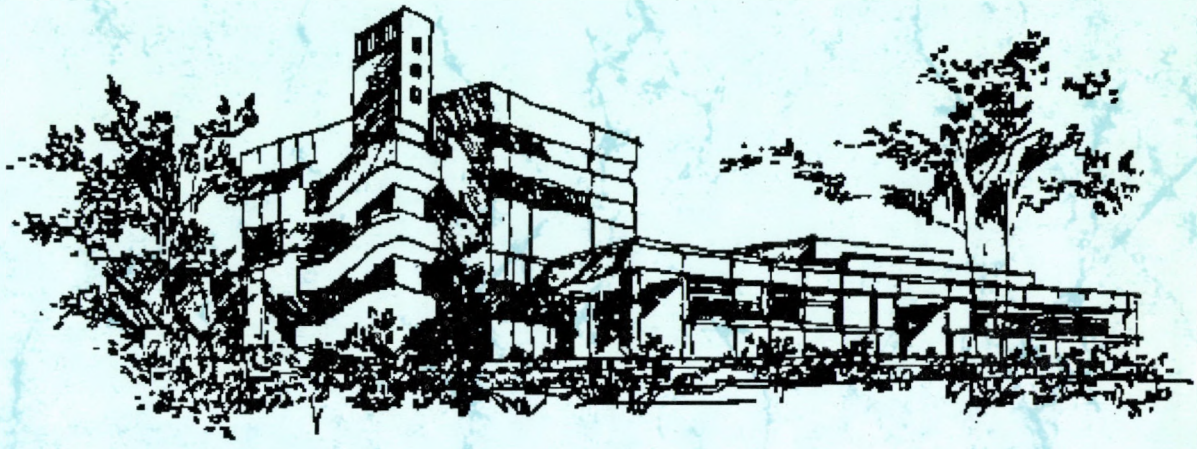
ATOMKI

ANNUAL REPORT 2002



INSTITUTE OF NUCLEAR RESEARCH
OF THE HUNGARIAN ACADEMY OF SCIENCES
DEBRECEN, HUNGARY

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Postal Address:
P.O.Box 51
H-4001 Debrecen
Hungary

Editor:
I. Rajta

HU ISSN0 0231 – 3596

Preface

One of the main themes of the year of 2002 was the preparation for taking a significant step. The *Tandetron*-based accelerator mass spectrometer (AMS) of Oxford University was to be replaced, and the old system was presented to this laboratory. A team of five went to Oxford to dissemble the machine, and they brought it home in two lorries just before the hard winter came round. The machine had been used in Oxford for some 20 years for radiocarbon dating. Our primary aim is also to use it for ^{14}C analyses, but, depending on the inflow of project money, we have more ambitious plans. The tandem accelatator itself works reliably up to 2.2 MV terminal voltage, and it may be transformed into a general-purpose accelerator of broad ion selection. It is set up such that its beam could be injected into the beam lines of the old 5-MeV Van de Graaff accelerator, which could make it possible to replace the latter when its time comes. The re-installation of the AMS is now is progress, but it is hampered by an enormous increase of demand for the beam-time of the old machine, which is run by the personnel who are to install the new one. We expect the installation will be completed in 2004.

Last year there were two winning projects with our participation in the major national scheme for the stimulation of research and development: *'PET Minicamera and R&D for the Techniques of Application'* and *'Hydroecology of River Tisza and of the Upper Tisza Area'*. We contribute to the first one by the construction of a miniature positron emission tomograph (PET) for experiments with small animals and by new radiopharmaceuticals for PET diagnostics of humans. The second project is concerned with the heavy-metal pollution of river Tisza caused by a gold mine on Romanian territory a few years ago. We have two jobs in this project: we examine water reservoirs near the river by mass spectrometry and analyse the heavy-metal content of the tissues of creatures by the ion microprobe. This report is the last on this project scheme for the time being: last year no new round was launched, so in the next number of Atomki Report there will be nothing to report on.

The most important event to take place here last year was the 17th International Nuclear Physics Divisional Conference of the European Physical Society (EPS) from 30th September to 4th October. The title of the conference was *Nuclear Physics in Astrophysics*. This meeting was originally to be held at Eilat, Izrael, a year before, but was cancelled because of security reasons. The proceedings have appeared in Vol. 719 of Nuclear Physics A. The conference was a huge success, owing, to a great extent, to the local organizers, *Zsolt Fülöp* and his aides. At the request of the nuclear astrophysics community, the Nuclear Physics Board of EPS has declared this meeting to be the first member of a European conference series. The second conference will also be held in Atomki. That will be in 2004.

The subject of the March Physics Days, the local 'public feast' of physics, was *The Earth We are Living on*. The lectures reviewed the physical features that make the Earth suitable for life, and the dangers coming from and going against our natural environment. There were talks about the radiations we are subjected to, about the aerosols we are inhaling, about earthquakes we are shattered by and about the phenomena, taking palce on the Earth, from which we can learn physics. But the summit of the Physics Days was that the ailing *George Marx*, Honorary President of the Roland Eötvös Physical Society, who died later, in December, delivered a most extensive version of his brilliant public lecture *Life in the Nuclear Valley*, in which he reviewed how life hinges on the fine-tuning of nuclear stability.

In 2002 we prepared a Hungarian version of the European exhibition *Radioactivity: a Facet of Nature*. The debut of the exhibition took place at the University of Debrecen in September. It was opened by Alessandro Pascolini, who masterminded the original version. The exhibition was visited by 5–10,000 people—school groups, families and individuals—and invoked general acclaim. A key point to its success was the enthusiasm of the members and students of the Department of Experimental Physics of the University and of Atomki. The exhibition has since then been put up at Paks, at Eötvös University, Budapest, and preparations are being made in another town, Baja, for showing it.

Last year saw the bicentenary of the birth of the greatest Hungarian mathematician, *János Bolyai*, a

pioneer in non-Euclidean geometry. A short memorial lecture was delivered at the Academy of Sciences by *András Prékopa*, and he delivered his lecture in full length in Atomki the following day.

The first scientific feat I should mention is that the great book on the *Structure of Atomic Nuclei* by *Professor Emeritus Instituti Tibor Fényes* appeared last year (Akadémiai Kiadó, Budapest). This 700-page long book gives a comprehensive overview of the state of the art of nuclear structure physics at the highest level. Due to the enormous growth and ramification of its subject, this book is unlikely to have any rival in the near future. It is esentially a theory book written by an experimentalist.

As for notable new results, I should mention that we have made a significant progress in the description of two-particle resonances. The problem of two particles moving in shell-model orbits that are embedded in the continuum has been solved in an ambitious theory of resonances, the Berggren theory. There are a number of interesting new effects found by our atomic physics experimentalists. I quote just one of them since it is especially intriguing. Electron loss spectra obtained in ion–atom collisions show a cusp-like peak at the electron velocity that is equal to the velocity of the incoming ion. In recent years a similar effect was observed for neutral atomic projectiles. Now—and that is what is really surprising—an even narrower characteristic cusp was found with a neutral molecular beam.

As to applied R&D, the environmental studies were most voluminous as usual, but there has been a breakthrough in another field. The expertise in vacuum technique and cryotechnology has been used in designing an instrument checking the vacuum-tightness of vessels to be used as parts of industrially produced machinery. The prototype has proved to endure the wear of the use on the production line.

The Szalay Prize of the Institute for basic research was awarded to *Dr. András T. Kruppa* for his theoretical studies of the structure of proton-drip-line nuclei. After the 'Physics Award' in 2001, *Prof. Zoltán Trócsányi* now won the more prestigious Award of the Academy for his results in the application of perturbative quantum chromodynamics. In 2002 one member of Atomki, *Dr. Béla Sulik* has been awarded the DSc degree. Last year a new *Professor Emeritus Instituti* award has been conferred. The recipient was *Prof. Gyula Csikai*, who had been the first deputy director of Atomki and head of the Section of Neutron Physics up to 1967, and then he became a professor at the Department of Experimental Physics of the University of Debrecen. He has always been in close contact with Atomki, but recently he has intensified his research at our cyclotron and has more time to engage in the matters of this Institute. We commemorated the 70th birthday of *Professor Emeritus Instituti Borbála Gyarmati*, who is founder of theoretical physics research in the Institute and headed the Section of Theoretical Physics for more than 20 years. We held an intimate commemoration in Atomki, and, to honour her and some other outstanding nuclear physicists of her generation, a public scientific session entitled *From Nuclei to the Stars—sic itur ad astra*, was also held at the Academy.

At the end of the year I was elected Co-chairman of the Council of the Heads of Research Institutions of the Academy. This is a consultative body comprising all directors of the institutes of the Academy and representatives of the university research groups supported by the Academy.

In August 2002 we lost our old friend, Dr. László Medveczky, at his age of 86. He was founder of the research and applications of nuclear track detection techniques in Atomki, which once was one of the most successful research fields here. He also was deputy director for several years. At the time of the foundation of the Institute he was already a senior researcher, and he witnessed the first three and a half decades of its history closely. He had a fantastic memory, and he was the person who knew probably all interesting anecdotes from that period. With his departure we lost a piece of our past.

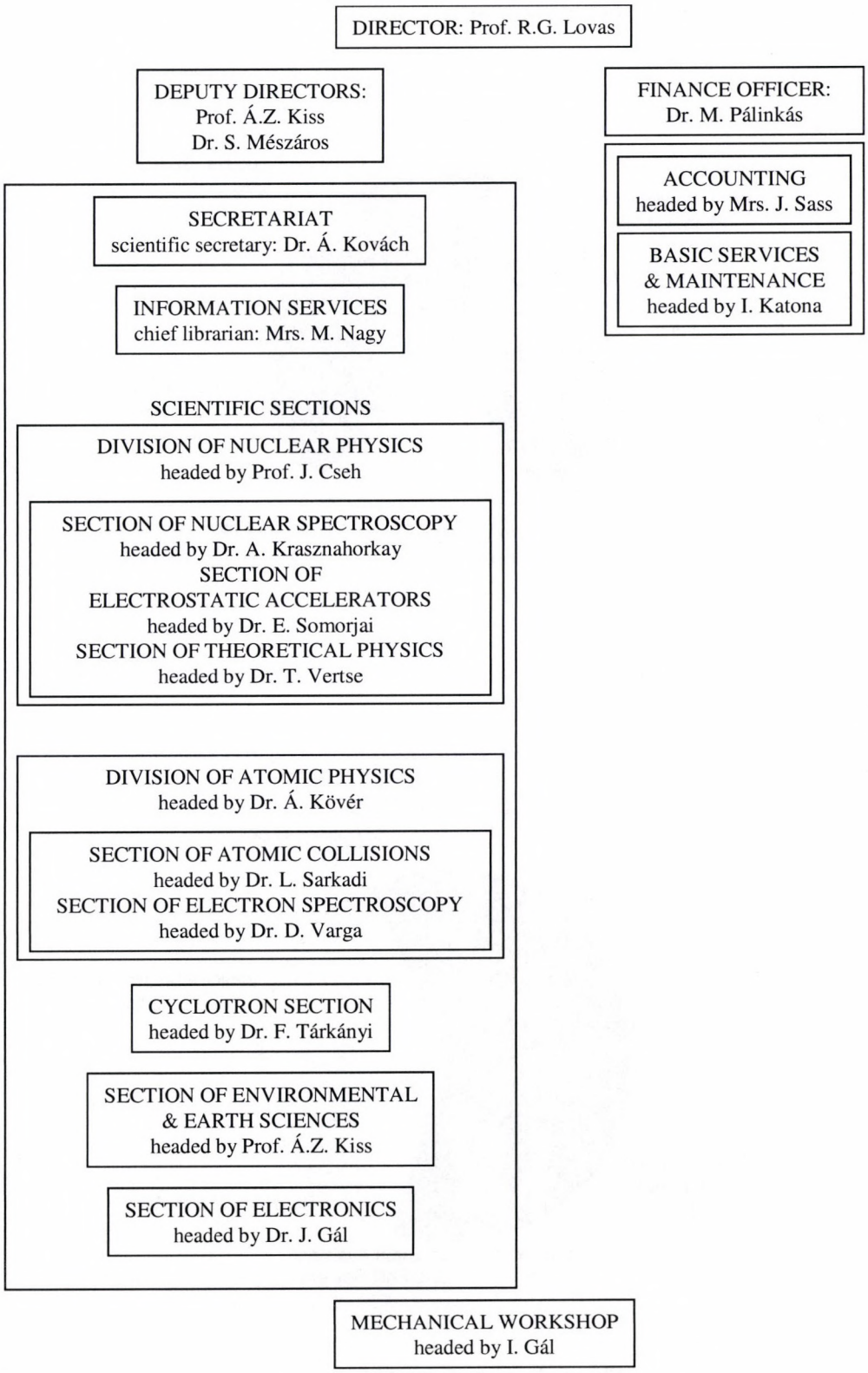
The financial and personnel conditions in 2002 are given in the pie charts to follow this Preface.

This Report, prepared in LaTeX, is available on the web at www.atomki.hu in PDF format.

Debrecen, 21 July 2003

Rezső G. Lovas
Director

Organizational structure of ATOMKI



Data on ATOMKI

At present the Institute employs 202 persons. The affiliation of personnel to units of organization and the composition of personnel are given below.

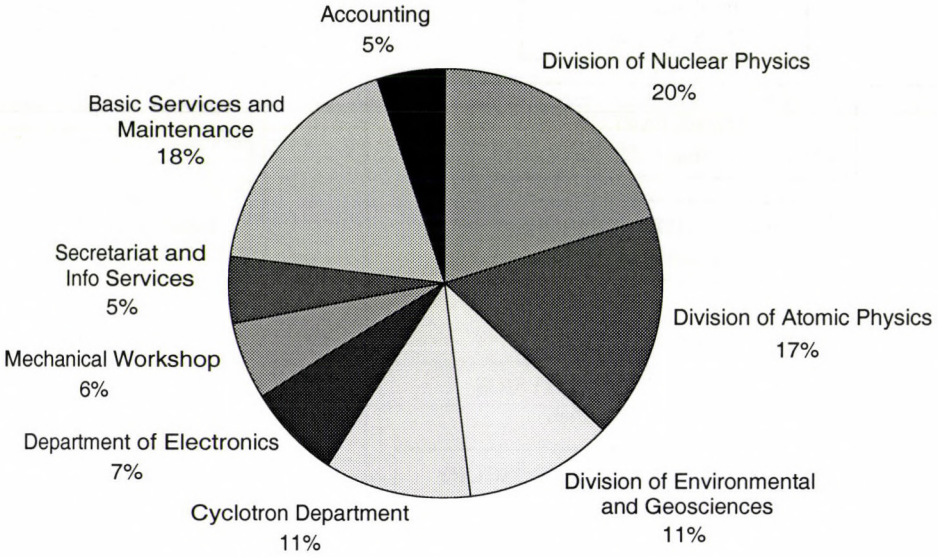


Figure 1. Affiliation of personnel to units of organization

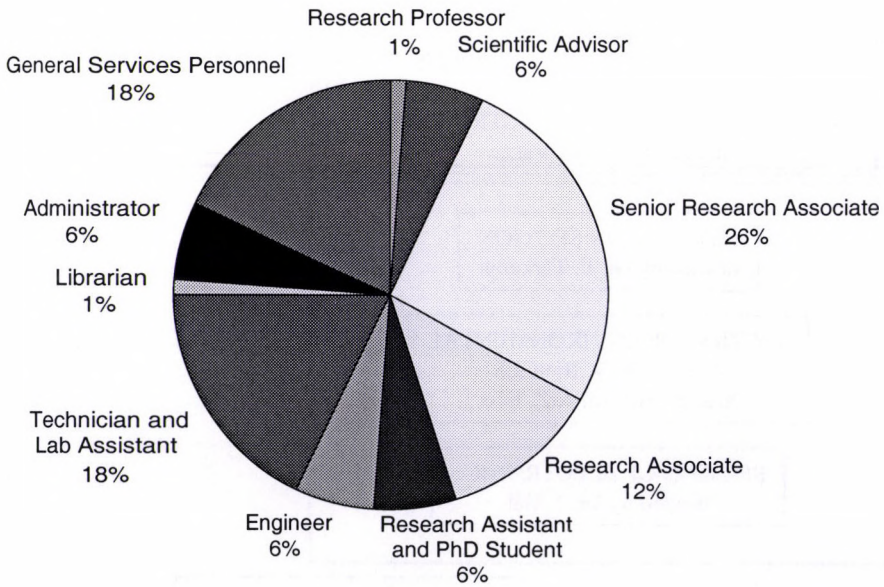


Figure 2. Composition of personnel

Finance

The total budget of the Institute for the year 2002 was 1024 million Hungarian Forints. The composition of the budget and the share of personnel expenditure within the budget are shown below.

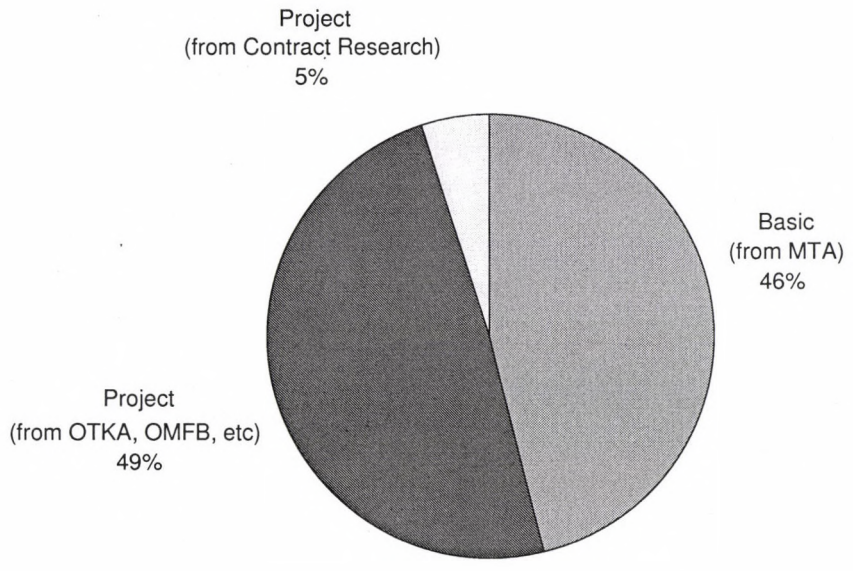


Figure 3. Composition of the budget of the Institute

MTA: Hungarian Academy of Sciences
OTKA: National Fund for Scientific Research
OMFB: National Committee for Technological Development

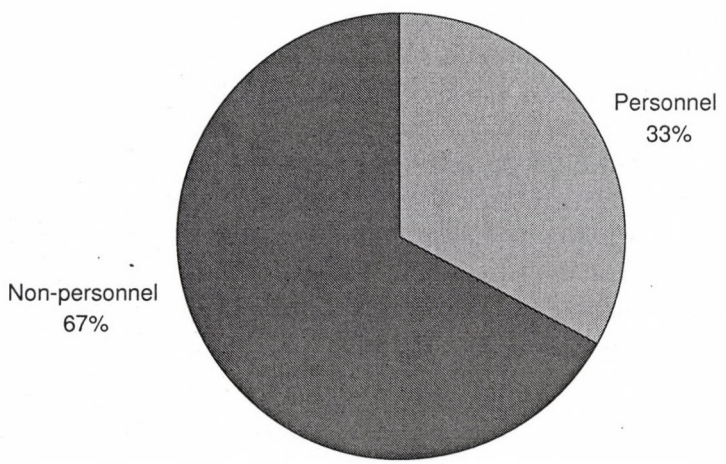


Figure 4. Breakdown of expenditure into personnel and non-personnel expenditures

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1.1 Specific aspects of $\mathcal{PT}$ symmetric potentials

G. Lévai, F. Cannata[a] *and A. Ventura*[b]

$\mathcal{PT}$ symmetric quantum mechanical potentials have a number of surprizing properties compared to conventional Hermitian problems. These one-dimensional potentials are invariant under the simultaneous action of the space and time reflection operations $\mathcal{P}$ and $\mathcal{T}$, and have the property $[V(-x)]^* = V(x)$. The first notable finding was that despite being complex, these potentials have real bound-state energy spectrum, unless $\mathcal{PT}$ symmetry is spontaneously broken (i.e. when the eigenfunctions are not eigenfunctions of the $\mathcal{PT}$ operator), in which case the energy spectrum contains complex conjugate pairs.

A natural development was the $\mathcal{PT}$ symmetrization of exactly solvable potentials. For most members of the *shape-invariant* potential class where the most well-known potentials belong, this can be done by introducing an imaginary coordinate shift $x \to x + \mathrm{i}\epsilon$, which cancels the singularity of the potentials at $x = 0$. Due to the less strict boundary conditions, $\mathcal{PT}$ symmetric potentials have two sets of normalizable solutions, which can be distinguished with the introduction of the quasi-parity quantum number $q = \pm 1$. Here we report on two specific aspects of shape-invariant $\mathcal{PT}$ symmetric potentials.

1. The interplay of $\mathcal{PT}$ symmetry and algebras related to solvable potentials. For many potentials the bound (and sometimes also the scattering) states can be assigned to irreducible representations of certain groups, and the group generators ladder between them. In this respect the doubling of the normalizable states is especially interesting, because it means that the algebra can be larger for $\mathcal{PT}$ symmetric potentials. We formulated differential realizations of the so(2,2) and so(4) algebras related to some shape-invariant $\mathcal{PT}$ symmetric potentials [1]. The ladder operators $J_\pm$ and $K_\pm$ were first-order differential operators and contained altogether ten independent functions, of which only two remained when the so(2,2) (or so(4)) commutation relations were enforced. One more function had to be used in order to bring the second-order Casimir invariant into a form compatible with the Hamiltonian (i.e. to eliminate the linear derivative term), so altogether the algebra was determined by a single independent function. The algebra contained the so(2,1)$\oplus$so(2,1) (or so(3)$\oplus$so(3)) subalgebra, where the two so(2,1) (or so(3)) algebras were generated by J_i and K_i, $i = +, -, z$. We also proved that $\mathcal{PT}(J/K)_\pm(\mathcal{PT})^{-1} = (J/K)_\mp$ and $\mathcal{PT}(J/K)_z(\mathcal{PT})^{-1} = -(J/K)_z$ hold.

2. $\mathcal{PT}$ symmetry breaking and the pseudo-norm for the Scarf II potential. Soon after the introduction of $\mathcal{PT}$ symmetry in quantum mechanics it was found that the inner product and the norm has to be redefined for systems with this property, and that the pseudo-norm derived this way has indefinite sign. More recently the interpretation of this result was put on a firm mathematical basis by demonstrating that $\mathcal{PT}$ symmetry is a special case of pseudo-Hermiticity. Besides the general mathematical formalism, however, practically there were no concrete examples with analytical expressions for the pseudo-norm. Therefore we determined the pseudo-norm for the (shape-invariant) $\mathcal{PT}$ symmetric Scarf II potential [2], which is a favourite testing ground of studies in this field. We proved the indefinity of the pseudo-norm, and also determined the normalization constants for the eigenfunctions of the real Scarf II potential for the first time. We also proved orthogonality relations for the Scarf II eigenfunctions both for unbroken and spontaneously broken $\mathcal{PT}$ symmetry.

a) Dipartimento di Fisica dell'Universitá and INFN, Bologna, Italy

b) Ente Nuove Tecnologie, Energia e Ambiente, and INFN, Bologna, Italy

[1] G. Lévai, F. Cannata and A. Ventura, J. Phys. A 35 (2002) 5041.

[2] G. Lévai, F. Cannata and A. Ventura, Phys. Lett. A 300 (2002) 271.

1.2 The interplay of supersymmetry and $\mathcal{PT}$ symmetry in quantum mechanics

G. Lévai and M. Znojil[a)]

The unusual features of $\mathcal{PT}$ symmetric potentials naturally raise the question how this symmetry is related to other symmetry concepts characterizing quantum mechanical potentials. One particularly interesting aspect of this question stems from the fact that $\mathcal{PT}$ symmetric potentials have *two* sets of normalizable solutions distinguished by the $q = \pm 1$ quasi-parity quantum number [1]. This also means that there are *two* nodeless normalizable solutions in these potentials (with principal quantum number $n = 0$ and $q = \pm 1$), and thus it is possible to define *two* superpotentials in the supersymmetric quantum mechanical (SUSYQM) formalism [2] as $W^{(q)}(x) = -\frac{\mathrm{d}}{\mathrm{d}x} \ln \psi_{0,-}^{(q)}(x)$, where $\psi_{n,-}^{(q)}(x)$ is the n'th normalizable wavefunction with quasi-parity q. The SUSYQM shift operators

$$A^{(q)} = \frac{\mathrm{d}}{\mathrm{d}x} + W^{(q)}(x) \qquad A^{\dagger(q)} = -\frac{\mathrm{d}}{\mathrm{d}x} + W^{(q)}(x)$$

then also carry the q quantum number. The "bosonic" Hamiltonian can be made independent of q if it is written in terms of the q-dependent factorization energy [2] $\mathbf{H}_- = A^{\dagger(q)} A^{(q)} + \varepsilon^{(q)} = A^{\dagger(-q)} A^{(-q)} + \varepsilon^{(-q)}$, where $\varepsilon^{(\pm q)} = E_{0,-}^{(\pm q)}$. Then its eigenvalue equation takes the form $\mathbf{H}_- \psi_{n,-}^{(q)} = [A^{\dagger(\pm q)} A^{(\pm q)} + \varepsilon^{(\pm q)}] \psi_{n,-}^{(q)} = E_{n,-}^{(q)} \psi_{n,-}^{(q)}$. The "fermionic" partner Hamiltonians, however, will depend on q: $\mathbf{H}_+^{(\pm q)} \psi_{n,+}^{(q)} = [A^{(\pm q)} A^{\dagger(\pm q)} + \varepsilon^{(\pm q)}] \psi_{n,+}^{(q)} = E_{n,+}^{(q)} \psi_{n,+}^{(q)}$. It is straightforward to prove that $\mathbf{H}_-$ and the $\mathbf{H}_+^{(\pm 1)}$ are isospectral, and the eigenstates of $\mathbf{H}_+^{(+1)}$ ($\mathbf{H}_+^{(-1)}$) are obtained by acting on the eigenstates of $\mathbf{H}_-$ with $A^{(+1)}$ ($A^{(-1)}$) [2]. The difference between the energy spectrum of $\mathbf{H}_+^{(+1)}$ and $\mathbf{H}_+^{(-1)}$ is that the energy level corresponding to the ground state of $\mathbf{H}_-$ with $q = 1$ is missing from the spectrum of $\mathbf{H}_+^{(+1)}$, while that corresponding to $q = -1$ is missing from the spectrum of $\mathbf{H}_+^{(-1)}$

As an illustration we considered the Scarf II potential [2] with superpotential $W^{(q)}(x) = -\frac{1}{2}(q\alpha + \beta + 1) \tanh x - \frac{\mathrm{i}}{2}(\beta - q\alpha) \mathrm{sech} x$. This generates the "bosonic" potential

$$V_-(x) = -\frac{(\alpha+\beta)^2 + (\alpha-\beta)^2 - 1}{4\cosh^2 x} + \frac{\mathrm{i}\sinh x}{2\cosh^2 x}(\beta+\alpha)(\beta-\alpha)$$

if the factorization energies are $\varepsilon^{(q)} = -\frac{1}{4}(q\alpha + \beta + 1)^2$. (Note that $V_-(x)$ remains unchanged when q is introduced via $\alpha \to q\alpha$.) The "fermionic" partner potentials are then

$$V_+^{(q)}(x) = -\frac{(q\alpha+\beta+2)^2 + (q\alpha-\beta)^2 - 1}{4\cosh^2 x} + \frac{\mathrm{i}\sinh x}{2\cosh^2 x}(\beta + q\alpha + 2)(\beta - q\alpha) \, .$$

The results obtained for the Scarf II potential have significantly different implications for unbroken and broken $\mathcal{PT}$ symmetry, corresponding to real and imaginary values of α [2]. In the former case the "fermionic" partner potentials $V_+^{(q)}(x)$ are $\mathcal{PT}$ symmetric, and the energy eigenvalues remain real. In the latter case, however, the coupling parameters of both the even and odd component of the potential become complex due to the imaginary value of α, therefore the "fermionic" potentials cease to be $\mathcal{PT}$ symmetric.

Recent preliminary results indicate that these findings based on the existence of the $q = \pm 1$ quasi-parity quantum number also hold for potentials outside the shape-invariant class. We found that the eigenstates of the $\mathcal{PT}$ symmetric generalized Ginocchio potentials can also be labelled with q, and its supersymmetrization leads exactly to the same results as those obtained for the shape-invariant Scarf II potential.

a) Nuclear Physics Institute of Academy of Sciences of the Czech Republic, Řež, Czech Republic

[1] G. Lévai, F. Cannata and A. Ventura, previous contribution in this volume.

[2] G. Lévai and M. Znojil, J. Phys. A 35 (2002) 8793.

2.1 A New Method for Lifetime Determination by Use of Gamma-Ray Spectroscopy at Intermediate Energies

Z. Elekes[b)], Zs. Dombrádi, A. Saito[a)], Zs. Fülöp, N. Aoi[b)], H. Baba[a)], K. Demichi[a)], J. Gibelin[c)], T. Gomi[a)], H. Hasegawa[a)], N. Imai[d)], M. Ishihara[b)], H. Iwasaki[d)], S. Kanno[a)], S. Kawai[a)], T. Kishida[b)], T. Kubo[b)], K. Kurita[a)], Y.U. Matsuyama[a)], S. Michimasa[d)], T. Minemura[b)], T. Motobayashi[b)], M. Notani[d)], T. Ohnishi[d)], H.J. Ong[d)], S. Ota[e)], A. Ozawa[b)], H.K. Sakai[a)], H. Sakurai[d)], S. Shimoura[d)], D. Sohler, E. Takeshita[a)], S. Takeuchi[b)], M. Tamaki[d)], Y. Togano[a)], K. Yamada[a)], Y. Yanagisawa[b)], K. Yoneda[b)]*

Nowadays in the radioactive beam experiments the lifetime of the nuclear states was deduced mainly from the excitation cross section of inelastic scattering, a method efficient in the 100 fs-100 ps region. In this report we propose a simple method to measure nuclear lifetimes in the 100 ps-10 ns region.

The method is based on the fact that the frequency of a γ ray emitted by a fast moving nucleus is Doppler-shifted. The amount of the Doppler shift does depend on the angle the γ ray was detected at. Assuming a very short lifetime, all the γ rays are emitted already from the target, and generate a narrow peak in a small detector. If the lifetime of the decaying state is not short enough, than the γ ray may be emitted at different distances downstream the target. Thus, the detectors, especially those at forward angles detect radiations from different directions, and because of this obeying different Doppler shifts. As a result, a low energy tail develops for the peaks, which may cause a broadening of the peak at shorter lifetimes or backward angles, and a characteristic peak shape for longer lifetimes and forward angles. In order to demonstrate the effectiveness of the method, we measured the known lifetime of the first exited state of ^{15}C.

The experiment was performed at RIKEN. A ^{40}Ar primary beam of 94 A MeV energy and 60 pnA intensity bombarded a 0.5-mm-thick ^{9}Be target. The secondary beam consisting of ^{15,16}C isotopes, was separated by the RIPS

fragment separator. The particle identification of the secondary beam was made by using the information on the beam energy loss and the the particle time-of-flight between plastic scintillators. The radioactive beam bombarded a liquid hydrogen target with a 140 mg/cm^2 thickness. The scattered particles were detected by a 2×2 silicon telescope matrix. An array of NaI(Tl) detectors consisting of 13 layers was placed around the target to detect the γ rays emerging from the inelastically scattered beam particles.

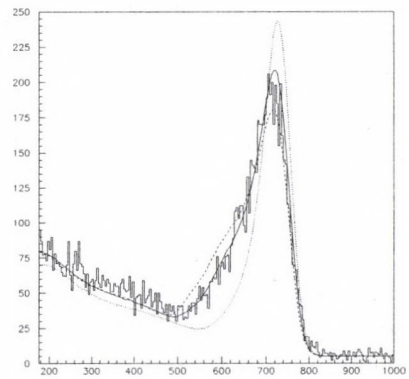

Figure 1. Gamma-ray peak shapes obtained from the decay of the first excited state ^{15}C compared with those calculated with GEANT assuming 2.61 ns (solid), 2.1 ns (dashed) and 3.1 ns (dotted) lifetimes.

The spectra taken by the detectors in the last 3 layers downstream the target were added to increase the statistics. A GEANT simulation was performed to deduce the precise lifetime and determine the uncertainty of our method. The results are shown in Fig.1. The smaller the assumed lifetime, the narrower the peak is. According to a chisquare analysis the 2.61 ns lifetime could be determined at +20%/-15% accuracy with our statistics, and the curves for them are similar to those in Figure 1.

*) On leave from ATOMKI
a) Rikkyo University, Tokyo, Japan
b) RIKEN, Wako-shi, Japan
c) IPN, Orsay, France
d) University of Tokyo, Tokyo, Japan
e) Kyoto University, Kyoto, Japan

2.2 Correlation between the momentum transferred by a projectile like fragment and its intrinsic angular momentum: a method for spin determination

Zs. Dombrádi, D. Sohler, J. Timár, F. Azaiez[a)], O. Sorlin[a)], F. Amorini[a)], D. Baiborodin[b)], A. Bauchet[c)], M. Belleguic[a)], C. Borcea[e)], C. Bourgeois[a)], Z. Dlouhy[g)], C. Donzaud[a)], J. Duprat[a)], D. Guillemaud-Mueller[a)], F. Ibrahim[a)], M.J. Lopez[f)], R. Lucas[h)], S.M. Lukyanov[b)], J. Mrazek[g)], Yu.-E. Penionzhkevich[b)], L. Petizon[a)], M.G. Saint-Laurent[f)], F. Sarazin[c)], J.A. Scarpaci[a)], M. Stanoiu[f)], C. Stodel[a)], C. Theisen[d)], G. Voltolini[f)]

To determine the spin of a state by use of in-beam γ-ray spectroscopy at low energies one can rely on the reaction mechanism and exploit the spin and bombarding energy dependence of the cross section of excitation of different states. The slope of the excitation functions of the different states is characteristic for the spin of the state. Increasing the energy more angular momentum is transferred into the compound nucleus, resulting in higher production cross sections for higher spin states than for the lower ones.

At intermediate energy two processes contribute to the angular momentum transfer. In a grazing collision because of the friction a collective angular momentum is generated, while some momentum is lost. The other part of the angular momentum arises as sum of single particle angular momenta taken away by the fragment removed from the projectile. The directions of the generated fragmentation and the frictional angular momenta are the same for the case when the projectile is slowed down, while they are opposite if the projectile is speeded up. Thus, one can expect that there is a correlation between the velocity of the projectile like fragment and its angular momentum. It has already been shown that the use of the low energy tail of the momentum distribution is much more favorable for production of high spin isomers than the middle part, supporting the above hypothesis.

We studied the relative excitation cross section of states with different spin in a reaction where a beam of ^{36}S with 77 MeV/u energy was fragmented on a ^{9}Be target. The momentum of the fragments, as well as, their masses and charges were measured by use of the big magnetic spectrograph SPEG. The relative excitation of different states was deduced from the intensities of γ rays originating from their deexcitation measured by 74 BaF_2 and 4 Ge detectors.

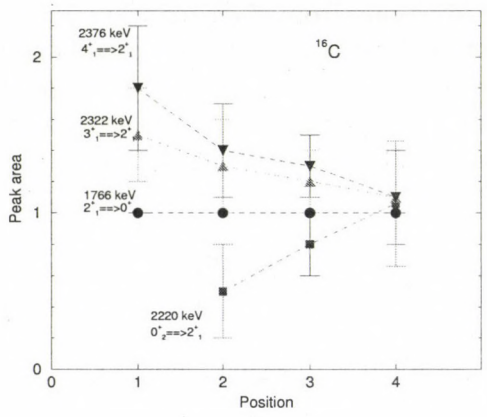

Figure 1. Relative excitation cross sections of γ rays of ^{16}C in the ^{9}Be + 77 MeV/u ^{36}S reaction as a function of the momentum of the fragment.

In Figure 1 we show the gamma ray intensities as a function of the momentum of the fragment. We used 4 cuts on the momentum distributions: 2 at the low and high energy tails and 2 in the middle positions. The peak areas obtained were normalized to the yield of the γ ray from the 2_1^+ state. It can be seen that there are clear tendencies in the relative cross sections, showing an angular momentum dependence in the slope of the excitation functions. Similarly to the case of low energy reactions, this feature can be used to determine the spin of excited states obtained in fragmentation reactions.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France

2.3 Angular distribution ratios: a method for determining γ-ray multipolarities in projectile fragmentation reactions

Zs. Dombrádi, D. Sohler, J. Timár, F. Azaiez[a], O. Sorlin[a], F. Amorini[a], D. Baiborodin[b], A. Bauchet[c], F. Becker[d], M. Belleguic[a], C. Borcea[e], C. Bourgeois[a], Z. Dlouhy[g], C. Donzaud[a], J. Duprat[a], D. Guillemaud-Mueller[a], F. Ibrahim[a], M.J. Lopez[f], R. Lucas[h], S.M. Lukyanov[b], V. Maslov[b], J. Mrazek[g], Yu.-E. Penionzhkevich[b], L. Petizon[a], M.G. Saint-Laurent[f], F. Sarazin[c], J.A. Scarpaci[a], M. Stanoiu[f], G. Sletten[i], C. Stodel[a], C. Theisen[d], G. Voltolini[f]

The angular distribution of a γ ray emitted from an aligned state is inhomogeneous and its pattern is characteristic for the amount of angular momentum transferred by the γ transition.

At intermediate energies the typical reaction mechanism is the fragmentation, where a cluster of nucleons is removed from the projectile in the abrasion process, while it is assumed to behave as a spectator. The nucleons are transferred from nuclear surface, thus a connection between the momentum transferred and the direction of the angular momentum generated can be assumed. In such collisions, where the speed of the projectile changes, the direction of the transferred momentum is parallel with the beam direction, and the generated angular momentum is perpendicular to it. For most of the fragments the momentum is only slightly changed in the reaction, thus the momentum of the transferred particles is more or less orthogonal to the beam direction resulting in an angular momentum parallel with the beam direction. Depending on the relative weight of the different components 15-35% alignment of different fragments have already been observed, suggesting a possibility for measuring inhomogeneous γ-ray angular distribution, useful for multipolarity determination.

To check for the inhomogeneity of the γ distribution a ^{9}Be target of 2.76 mg/cm^2 thickness was bombarded by a $^{48}Ca^{19+}$ beam of 60.3 MeV·A energy and 15 nAe intensity. Angular distributions of the strongest γ transitions were analysed and have been found to be non-isotropic. This fact gives a clue on angular momentum orientation in the fragmentation reaction at intermediate energy. The γ-ray detectors were placed at three different angles, so we could deduce γ-ray intensity ratios for two pairs of angles. The ratios obtained were normalized to that of the 1577 keV stretched E2 transition of ^{46}Ar. Transitions from all the fragments were analysed and the obtained anisotropy ratios have been found to form two groups as it can be seen in Fig. 1. All the known stretched E2 transitions cluster within one group, while some transitions in odd fragments have anisotropy ratios within a second group. We can therefore distinguish between stretched quadrupole and stretched dipole transitions. The calculated theoretical values of the anisotropy ratios for stretched quadrupole and stretched dipole transitions have been found to be in agreement with the measured ones assuming an orientation of the order of 50±20%.

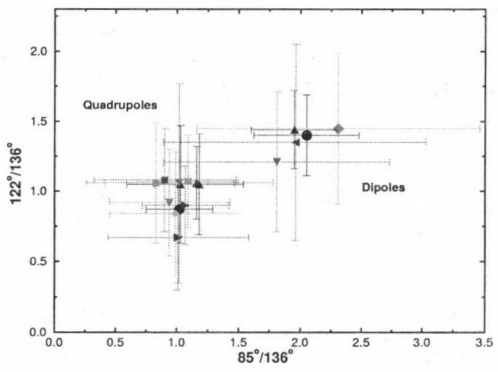

Figure 1. Experimental angular distribution ratios obtained from fragmentation of the ^{48}Ca beam on ^{9}Be.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France
i) NBI, Copenhagen, Denmark

2.4 Electron screening in the d(d,p)t reaction for deuterated metals

Gy. Gyürky, Zs. Fülöp, E. Somorjai, for the LUNA collaboration

For most nuclear physics purposes a nuclear reaction can be regarded as a process between two bare nuclei i.e the electron cloud surrounding the target nucleus and in some case the projectile can be neglected. However, in nuclear astrophysics, the cross section of some nuclear reactions are to be measured at very low energies where the above statement does not hold. The electron clouds surrounding the interacting nuclides act as a screening potential: the projectile effectively sees a reduced Coulomb barrier, both in height and radial extension. This, in turn, leads to a higher cross section for the screened nuclei, $\sigma_s(E)$, than would be the case for bare nuclei, $\sigma_b(E)$. This electron screening effect can be characterized by the electron screening potential energy, U_e [1].

Recently, the electron screening effect in d(d,p)t has been studied for the metals Al, Zr, and Ta [2], where the deuterated metals were produced via implantation of low-energy deuterons. The resulting U_e values ($U_e = 190 \pm 15$, 297 ± 8, and 322 ± 15 eV for Al, Zr, and Ta, respectively) are about one order of magnitude larger than the value found in a gas-target experiment [3]: $U_e = 25 \pm 5$ eV. Moreover, the values are much larger than the theoretical upper limit (the so called adiabatic limit), which is for this reaction 52 eV.

This surprising result motivated the present systematic work. More than 25 deuterated metals and 15 insulators/semiconductors have been studied at the 100 kV accelerator of the Ruhr-Universität Bochum. Many of the investigated metals exhibited a large (several hundreds of eV) electron screening supporting the validity of the above cited results. Insulators and semiconductors showed a normal "gaseous" behaviour i.e. the U_e values are below 100 eV.

As an example, fig. 1 shows the astrophysical S-factor of the d(d,p)t reaction measured in deuterated Ta. The measured points clearly show the exponential increase at low energies. The derived screening potential is $U_e = 340 \pm 24$ which is consistent with the previous measurement [2].

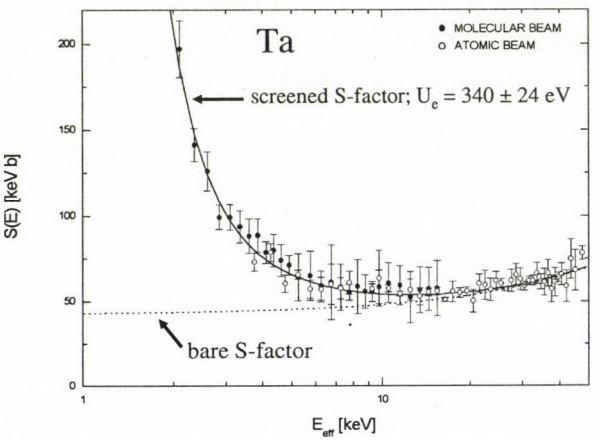

Fig. 1. Measured astrophysical S-factor of the d(d,p)t reaction in deuterated Ta

So far there is no explanation to this enhanced electron screening. Several possible reasons have been considered (including the thermal motion of target atoms, channeling, diffusion, Fermi-shuttle mechanism, etc. [4]) but none of them could explain the results. Further experimental work is in progress which involves additional elements of the periodic table including the lanthanides. The studies will use also target compounds, such as metal oxides. The temperature dependence of the U_e value will also be measured. The detailed description of the experimental set-up and the results obtained so far can be found in a recent paper [4].

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2.5 α-nucleus optical potential measurements for the astrophysical p-process

Zs. Fülöp, Gy. Gyürky, E. Somorjai, Z. Máté, L. Zolnai, D. Galaviz[a)], *M. Babilon*[a)], *R. Hillier*[a)], *P. Mohr*[a)], *A. Zilges*[a)] *and T. Rauscher*[b)]

The heavy, proton-rich nuclei (p-nuclei) are produced by the so called astrophysical p-process during the explosive nucleosynthesis of massive stars. This process involves γ-induced reactions on abundant, neutron-rich s-process isotopes. In order to derive correctly the abundance distribution of the proton-rich nuclei, it is necessary to know the reaction rates for the involved photon-induced reactions at the astrophysical energy of interest, close to the Gamow-window. Actually, almost none of these reaction rates has been determined experimentally, and therefore astrophysical calculations are based on statistical model calculations.

The (γ,α) reaction rates show a strong dependence on the chosen α-nucleus potential, which makes them of special interest. The α-nucleus potentials can be determined with α elastic scattering experiments. The potential can be derived from the difference between the measured and the pure Rutherford elastic scattering cross sections as a function of the scattering angle. Using this technique, the α-nucleus potentials of two proton rich nuclei (^{144}Sm and ^{92}Mo) have been determined in the ATOMKI in the recent years [1,2]. These potentials have been used to calculate the (α,γ) reaction cross sections, and their inverse (γ,α) reaction rates can be calculated using detailed balance.

The most recent elastic scattering experiment aimed to determine the optical potential of two isotopes of the same element having very different neutron numbers. For this purpose the ^{112}Sn and ^{124}Sn isotopes were investigated. The angular distributions of the elastically scattered α particles were measured at the Cyclotron Laboratory of ATOMKI, Debrecen using an α-beam of 14.5 and 19.5 MeV. The highly enriched targets were set in the center of the 78 cm scattering chamber, and different spectra were registered at angles between $20° \leq \vartheta_{lab} \leq 170°$. Fig. 1 shows two typical spectra taken at forward and backward angles.

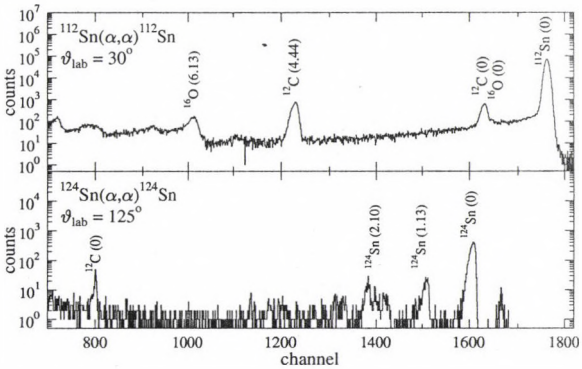

Fig. 1. Spectra of the ^{112,124}Sn(α,α)^{112,124}Sn reaction at $E_{c.m.}$ = 19 MeV. The peaks corresponding to the Sn isotopes, the C backing, and the O content of the target can clearly be seen.

Experimental cross sections were derived and normalized to the Rutherford cross section for the two angular distributions. At very backward there is a difference of about 25 % between the normalized cross sections of ^{112}Sn and ^{124}Sn. This fact may help to understand correctly the behaviour of the α-nucleus potentials along an isotopic chain.

The final analysis and the determination of the optical potentials are still in progress.

a) Institut für Kernphysik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany

b) Institut für Physik, Universität Basel, CH-4056 Basel, Switzerland

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2.6 Study of proton beam induced gamma background in metallic backings

Gy. Gyürky, Zs. Fülöp, E. Somorjai, for the LUNA collaboration

During most of its life, a low mass star burns H in the center via the pp chain. However, when the central H mass fraction reduces down to 0.1, the nuclear energy produced by the H-burning becomes not sufficient and the stellar core must contract to extract some energy from its gravitational field. Then, the central temperature (and the density) increases and the H-burning switches from the pp-chain to the more efficient CNO-burning. Thus the escape of the star from the Main Sequence is powered by the onset of the CNO burning, whose bottleneck is the $^{14}N(p,\gamma)^{15}O$ reaction [1].

The minimum energy explored so far in nuclear physics laboratories for this reaction is $\simeq 200$ keV, well above the region of interest for the CNO burning in astrophysical condition (20-80 keV), so that the values used in stellar model computations are largely extrapolated. Thus direct measurements of the $^{14}N(p,\gamma)^{15}O$ reaction at very low energies are needed [2,3].

The 400 kV LUNA2 accelerator facility installed at the Laboratori Nazionali del Gran Sasso provides a unique possibility to study this reaction at very low energies. Due to the extremely low cosmic background, the high energy γ-rays emerging from the $^{14}N(p,\gamma)^{15}O$ reaction can be measured even at very low intensities. However, the presence of light element impurities in the targets can cause severe problems since the proton beam can induce high energy γ-radiation on these impurities. Therefore it is of utmost importance to study these impurities and to choose the way of target preparation where the beam induced background is minimized. Moreover, the study of target stability is also important, since the low cross sections necessitate very long irradiations with high beam current. For the background tests solid state N targets have been produced with three different procedures: implantation, evaporation and sputtering. The implanted ones were produced at the accelerator of the Centro de Fisica Nuclear da Universidade de Lisboa, bombarding Ti, Cu and Ta backings with an isotopically pure ^{14}N low energy beam. Evaporated targets were prepared in ATOMKI evaporating a thin layer of Ti on Ta backings and exposing the heated Ti layer to N gas with pressure of 50 torr. Sputtered (deposited) targets were obtained by the RF magnetron sputtering technique at the Laboratori Nazionali di Legnaro.

The $^{14}N(p,\gamma)^{15}O$ reaction has a resonance at $E_p = 278$ keV. This resonance makes it possible to measure the target stability. We found that the evaporated TiN targets on Ta backings have the most uniform number density profile and withstand many days of beam bombardment with several hundreds of μA without any significant deterioration.

Due to their relatively low Coulomb barrier the presence of light-element impurities gives the biggest contribution. In the course of our studies in the range of proton energies between 140 keV and 400 keV the most relevant reactions on possible contaminants are $^{11}B(p,\gamma)^{12}C$, $^{19}F(p,\alpha\gamma)^{16}O$ and $^{18}O(p,\gamma)^{19}F$. All these reactions emit γ-rays with energies above 4 MeV and show resonance structures in the relevant range of proton energies. As for the beam induced background the sputtered targets proved to be the best.

On the base of the work presented in this contribution it has been possible to develop reliable target which allows to measure the reaction $^{14}N(p,\gamma)^{15}O$ at proton energies as low as 140 keV. Future experiments at LUNA2 will also largely benefit of this knowledge.

The research was supported in part by TARI HPR-CT-2001-00149.

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2.7 The pionic-hydrogen experiment at PSI

S. Biri, M. Demeter[a], L. Simons[b]

At the Paul Scherrer Institute (PSI, Switzerland) an experiment is presently being set up [1] which intends to determine the strong interaction shift and width of the pionic hydrogen atom ground state by measuring Lyman X-rays with a high resolution Bragg crystal spectrometer. The experiment combines the use of the most intensive pion beam (more than 10^8 pions/s at a momentum of 100 MeV/c) produced by a proton beam with a superconducting (SC) cyclotron trap to stop pions in dilute matter. For the analysis and the detection of the X–rays spherically bent quartz crystals (diameter 100 mm with a curvature radius of 3000 mm) are used together with state of the art CCD detectors. The binding energy of the p-π^- ground state is about 3228 eV and the expected strong interaction shift and width are about 7 eV and 1 eV, respectively. They both should be determined with a relative accuracy of about one percent, which certainly represents a challenge to present experimental techniques. It is therefore intended to tune and measure the resolution and the response function of the crystal off-beam with X-rays of single electron ions (e.g. Ar^{17+}).

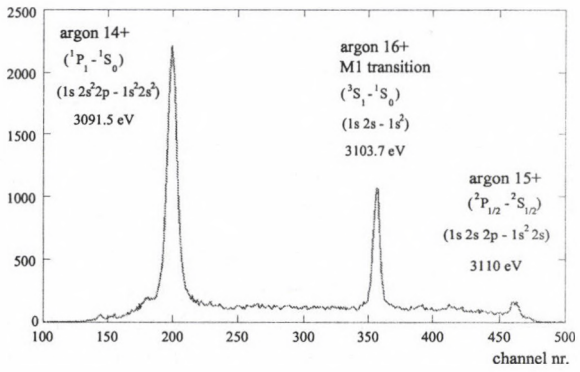
The most promising solution for this calibration purpose is an electron cyclotron resonance (ECR or ECRIS) ion source. In an ECRIS the ion motion is decoupled from the electron motion to a high degree. The ions have kinetic energies of only some eV and therefore a Doppler broadening of the X-rays is negligible.

Therefore it was decided to build an Electron Cyclotron Resonance Ion Trap (ECRIT) at PSI to produce X-rays coming from H-like heavy ions. In an ECRIT there is no ion extraction contrary to the usual ECRISs. The SC cyclotron trap magnet originally developed in PSI for high energy experiments was transformed into an ECRIT. The details of the magnetic calculations and of the whole design is presented here [2].

The PSI-ECRIT was put into operation recently and argon plasmas were successfully produced with different ionisation degree.

After some tuning tests the behaviour of the ECRIT was gradually better and finally the M1 transition $^3S_1$-$^1S_0$ at 3104 eV as well as the E1 transition $^1P_1$-$^1S_0$ at 3140 eV of Ar^{16+} could be observed (see figure). The magnetic dipole $^3S_1$-$^1S_0$ transition of the helium-like argon (lifetime 0.21 μs) with a peak/background ratio of 8:1 with an intrinsic width of about 40 meV was used to successfully characterize two different spherically bent Bragg crystals. The characterization of the two crystals could be performed in about ten hours each. This is in contrast to a time of about two weeks of continuous measurement needed for a characterization with exotic atoms. The use of an ECR device as a source for X-rays is also preferable compared to a synchrotron light source as the whole crystal is illuminated fully thus establishing similar conditions as in an experiment with X-rays of exotic atoms.

The pionic-hydrogen experiment itself therefore can be started in near future.



a) University of Debrecen, Debrecen, Hungary

b) Paul Scherrer Institut, Villigen PSI, CH5232 Villigen, Switzerland

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2.8 An e^+e^- study of elusive decays in ^{12}C and ^{16}O

F.W.N. de Boer[a,d], K. Bethge[a], H. Bokemeyer[c], M. Csatlós, Z. Gácsi, J. Gulyás, H. Frayquin[b], M. Hunyadi, A. Krasznahorkay, Z. Máté, K.A. Müller[a], K.E. Stiebing[a] and J. van Klinken[b]

A new series of dedicated experiments [1] has been performed at the AVF-cyclotron in Debrecen using the electron-positron spectrometer previously installed at the Van de Graaff. accelerator of the Institut für Kernphysik in Frankfurt [2]. The aim of the experiments is to search for elusive decay modes from unnatural parity states with T=0 in ^{12}C and ^{16}O. In particular, we like to confirm or refute a signal of a purported short-lived neutral isoscalar pseudoscalar boson with a mass of ~9 MeV/c^2 in competition with IPC (Internal Pair Creation) of high-energy isoscalar magnetic nuclear transition.

The $^{12}C(p,pe^+e^-)^{12}C^*$ and the $^{16}O(p,pe^+e^-)^{16}O^*$ reactions populating well known unnatural parity states with T=0 in ^{12}C and ^{16}O have been investigated at 16.5 MeV proton energy. For energy and efficiency calibration of the pair-spectrometer, use was made of the $^{19}F(p,\alpha e^+e^-)^{16}O^*$ reaction at 3.5 and 5.5 MeV proton energies. Targets were prepared at KVI and consisted of self-supporting carbon, Ta_2O_5 and BaF_2 with thicknesses varying between 1 and 3 mg/cm^2.

Results of the different experiments show composite structrured sum-energy spectra. Due to the good energy resolution of the detectors (~7%)the various magnetic transitions can uniquely be identified and their angular e^+e^- correlations accordingly measured. In ^{16}O, the e^+e^- sum-peak is identified of the forbidden $0^-\rightarrow 0^+$ transition [3] depopulating the $I^\pi=0^-$, T=0 level at 10.96 MeV. An early claim for an observation [5] of this transition has been contested later [6].

The present result enables us *for the first time* to determine of the angular distribution of a magnetic monopole transition which has, in the absence of any known cases, theoretically [7] not been taken into consideration. A first analysis shows that the magnetic monopole shape follows the characteristic $(1 + cos\theta)$ behavior of an electric monopole transition till the six largest correlation angles covered by our experimental setup ($86° \leq \theta \leq 134°$), where a dramatic increase in pairs suggests an interference of IPC with the allowed e^+e^- decay of an elusive 9 MeV/c^2 X-boson. In Fig.1, right: the low-energy, low-spin level scheme of ^{16}O is displayed. In left: sum-energy spectrum is shown for the ^{16}O reaction at the pair opening angle of 122.6°. The sum-line of the 10.96 MeV M0 transition is clearly present. Moreover, it becomes more pronounced for pairs with almost equal energy.

The present observation appears to be in line with a prediction by Donnelly *et al.* [8] as far back as 1978, that isoscalar $0^- \rightarrow 0^+$ transitions are *'eminent'* sources for axion emission due to the prohibited second order mode of IPC. Keeping this in mind, if existing a prolific source for isoscalar X-boson emission has to be expected in the decay of the 0^-, T=0 level at 10.96 MeV in ^{16}O with the narrow width Γ_{cm} of (80±50) meV [9]. In particular, with the isospin hindered isoscalar M1 transition of 3.84 MeV to the 1^-, T=0 level at 7.12 MeV as the only allowed decay mode with a partial isoscalar transition strength [4] of ≈8 meV, ample space is left for an X -boson channel.

The results of the ^{12}C reaction fully support a previously proposed X-boson scenario [4]. The isoscalar M1 transition at 12.71 MeV in ^{12}C exhibits a significant e^+e^- excess to IPC at large correlation angles. A comparison of the data with GEANT-simulation yields a boson mass $m_X = (9.15 \pm 0.15)$ MeV/c^2. The inferred branching ratio with respect to the isoscalar 12.71 MeV M1 γ-ray of $(12\pm3)\times10^{-4}$ almost coincides with the value of $(7\pm3)\times10^{-4}$ reported [4] for the $^{11}B(d,ne^+e^-)^{12}C^*$ reaction.

A short-lived isoscalar *X*-boson with a mass of 9 MeV/c^2 might be associated with a light supersymmetric vector boson. This so-called *U*-boson was invoked by Fayet as the super-

symmetric partner of the massless spin-1/2 goldstino or the massive spin-3/2 gravitino [10].

a) Institut für Kernphysik der Wolfgang Goethe-Universität (IKF), D-60486 Frankfurt am Main, Germany

b) Kernfysisch Versneller Instituut (KVI), 9747 AA Groningen, The Netherlands

c) Gesellschaft für Schwerionenforschung (GSI), D-64291 Darmstadt, Germany

d) Nationaal Instituut voor Kernfysica en Hoge-Energie Fysica (NIKHEF), NL-1098 SJ Amsterdam, The Netherlands

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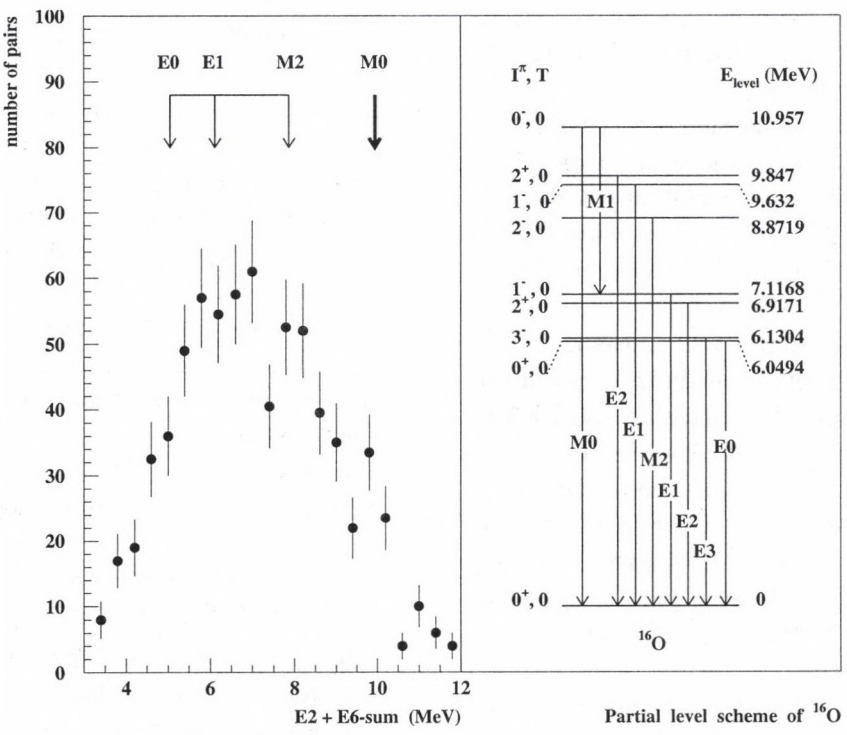

Figure 1. Left: sum-energy spectra of e^+e^- pairs following the $^{16}O(p,pe^+e^-)^{16}O$ reaction at 16.5 MeV at the pair opening angle of 122.6°. Transitions in ^{16}O of 6.05 MeV (E0), 7.12 MeV (E1), and 8.87 MeV (M2) contribute to the complex in the sum-energy spectrum from 4-9 MeV, while the 10.96 MeV (M0) transition is located in the 'low-background' region between 9 and 11 MeV. Right: Partial low-energy level scheme of ^{16}O

2.9 Different Deformations of Proton and Neutron Distributions in ^{16}C

Z. Elekes[a)], A. Krasznahorkay, H. Baba[b)], M. Csatlós, Zs. Dombrádi, N. Fukuda[a)], Zs. Fülöp, Z. Gácsi, J. Gulyás, N. Iwasa[c)], H. Kinugawa[b)], S. Kubono[d)], M. Kurokawa[d)], X. Liu[d)], S. Michimasa[d)], T. Minemura[d)], T. Motobayashi[a)], A. Ozawa[a)], A. Saito[b)], S. Shimoura[d)], S. Takeuchi[a)], P. Thirolf[e)], Y. Yanagisawa[a)], K. Yoshida[a)]*

Recent calculations of Horiuchi and Kanada-En'yo [1,2] suggest different deformations for proton and neutron distributions in carbon nuclei. The proton density is expected to be oblate, while the neutron densities vary with neutron numbers. For ^{16}C, a prolate neutron deformation with $\beta_n \sim 0.3$ is predicted.

To search for the difference in the proton-neutron density distributions, the angular distribution of the inelastically scattered ^{16}C nuclei was measured at a bombarding energy resulting in grazing collisions with the ^{208}Pb nuclei. By exploiting the Coulomb-nuclear interference effect in the inelastic channel populating the first 2^+ state, different angular distribution patterns are expected for different proton–neutron deformation ratios. With a proper precision the method may be sensitive also to the sign of the deformations.

The experiment was carried out at RIKEN, Japan. The description of the setup is detailed elsewhere [3], therefore we recall only some aspects here. The ^{16}C radioactive beam of 53 MeV/u was selected by the RIPS fragment separator.

The scattering angle was measured by using four parallel plate avalanche counters (PPAC). Due to multiple scattering and PPAC resolution the angular resolution was 0.28 ° at one sigma. A plastic scintillator hodoscope was used to identify the scattered particles. It covered the scattering angle of 4.5 degrees. Inelastic channel was selected using particle-gamma coincidences. The γ rays were detected by 68 NaI(Tl) scintillators.

The angular distribution of the scattered ^{16}C particles can be seen in Figure 1, where the indicated error bars correspond to the statistical uncertainty. The systematic errors, which arise from the uncertainty of background determination in the γ spectra is larger for the first few points (4-6%), and relatively small for the other angles (1-3%).

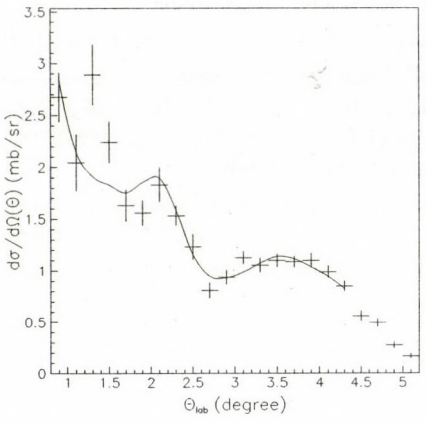

Figure 1. Angular distribution of ^{16}C nuclei in the inelastic channel. The solid line represents an ECIS calculation smoothed by a gaussian according to the angular resolution of the setup.

A set of ECIS calculation was also performed in order to interpret the angular distribution data. The best fit is plotted as a solid line in Figure 1. It shows fair agreement with the experimental data between 0.9 and 4.3 degrees.

Although the theoretical calculations are preliminary, the deformation parameters deduced indicate different proton and neutron deformations in ^{16}C. Possible effect of the γ-deformation [1,2] is under consideration. These data will be published elsewhere.

*) On leave from ATOMKI

a) RIKEN, Wako-shi, Japan

b) Rikkyo University, Tokyo, Japan

c) Tohoku University, Japan

d) University of Tokyo, Tokyo, Japan

e) Ludwig-Maximilians-Universitat, Germany

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2.10 Break up of the N=14 subshell closure in ^{20}C

Zs. Dombrádi, D. Sohler, J. Timár, Zs. Fülöp, A. Krasznahorkay, F. Azaiez[a], O. Sorlin[a], F. Amorini[a], D. Baiborodin[b], A. Bauchet[c], F. Becker[f], M. Belleguic[a], C. Borcea[e], C. Bourgeois[a], Z. Dlouhy[g], C. Donzaud[a], J. Duprat[a], D. Guillemaud-Mueller[a], F. Ibrahim[a], M.J. Lopez[f], M. Lewitowicz[f], R. Lucas[h], S.M. Lukyanov[b], J. Mrazek[g], Yu.-E. Penionzhkevich[b], L. Petizon[a], P. Roussel-Chomaz[f], M.G. Saint-Laurent[f], F. Sarazin[c], H. Savajols[f], J.A. Scarpaci[a], M. Stanoiu[f], C. Stodel[a], C. Theisen[d], G. Voltolini[f]

The high energy of the 2^+_1 state in ^{22}O, as well as the low B(E2) value associated with its γ decay clearly indicate a subshell closure at N=14 at Z=8, which survives at Z=9 and to some extent also at Z=10.

To study the stability of the N=14 subshell closure at lower Z values the excited states of ^{21}N and ^{20}C were investigated by use of in-beam γ spectroscopy. Spectra were collected from the fragmentations of a ^{36}S beam, as well as from the fragmentation of a mixture of radioactive beams of ^{25,26}Ne, ^{27,28}Na, ^{29,30}Mg produced by the fragmentation of a high intensity (400 pnA) ^{36}S beam. A γ array, composed of 74 BaF_2 christals was applied to collect the γ rays in coincidence with the fragments detected through the SPEG spectrometer. From the analysis of the γ-ray–fragment coincidences, γ rays were assigned to the decay of excited states in ^{21}N and from the radioactive beam experiment also in ^{20}C. The 15 counts at 1588(20) keV energy in ^{20}C, assigned to the 2^+ to 0^+ transition have been obtained from a total of 189 ^{20}C nuclei produced.

The proposed level schemes are show in Fig. 1. In ^{21}N the states at 2400 and 2914 keV were observed only in the radioactive beam experiment, while the one at 3570 keV was produced only by use of the stable beam. The first 3 excited states in ^{21}N follow the experimental systematics of ^{17,19}N, and are expected to correspond to the coupling of the $p_{1/2}$ proton to the 2^+ state of the core and to the proton $d_{5/2}$ single particle excitation, respectively. It is clearly seen that the 2^+_1 energy assumed in ^{21}N is that of ^{20}C, which is about a factor of two lower than the energy of 2^+_1 state in ^{22}O. ^{21}N seems to follow both of its neighbors as a doublet of states, which may correspond to the coupling of the $1/2^-$ ground state to the 2^+_1 of ^{22}O, was observed as well.

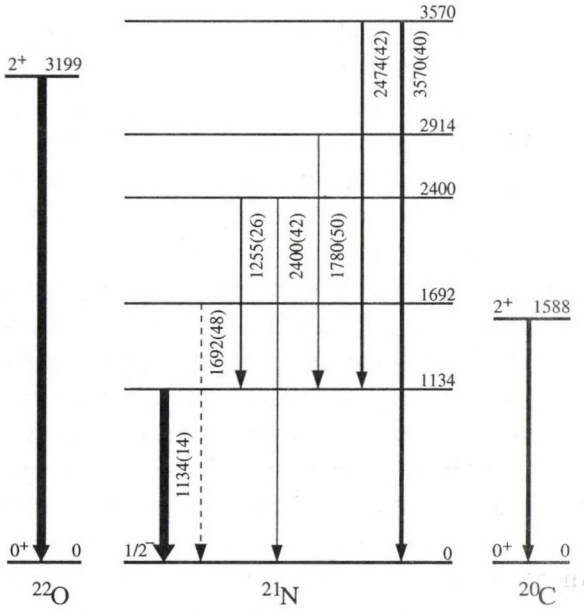

Figure 1. Systematics of the energy of excited states in neutron rich N=14 nuclei observed in the present study.

The break down of the N=14 subshell closure is caused by the sinking of the neutron $s_{1/2}$ single particle state below the $d_{5/2}$ one when two protons are removed from the $p_{1/2}$ orbit. This effect is visible already in the difference between the spectra of ^{17}O and ^{15}C. Furthermore, it can be traced back to the effect of the spin dependent and tensor components of the effective proton-neutron interaction.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France

2.11 Search for bound excited states in ^{23,24}O

Zs. Dombrádi, D. Sohler, J. Timár, Zs. Fülöp, A. Krasznahorkay, F. Azaiez[a], O. Sorlin[a], F. Amorini[a], D. Baiborodin[b], A. Bauchet[c], F. Becker[f], M. Belleguic[a], C. Borcea[e], C. Bourgeois[a], Z. Dlouhy[g], C. Donzaud[a], J. Duprat[a], D. Guillemaud-Mueller[a], F. Ibrahim[a], M.J. Lopez[f], M. Lewitowicz[f], R. Lucas[h], S.M. Lukyanov[b], J. Mrazek[g], Yu.-E. Penionzhkevich[b], L. Petizon[a], P. Roussel-Chomaz[f], M.G. Saint-Laurent[f], F. Sarazin[c], H. Savajols[f], J.A. Scarpaci[a], M. Stanoiu[f], C. Stodel[a], C. Theisen[d], G. Voltolini[f]

Shell model calculations predict N=16 to be a closed shell in the oxygen isotopes. Recent mass measurements seem to confirm this prediction. To see how large the N=16 gap is energies of the excited states in ^{24}O or ^{23}O should be known. The need for more experintal data is supported by the fact that different effective interactions lead to different shell gaps, some of which result in no bound state in any of ^{23,24}O, while some allow for one bound state. The situtation is even more complicated, since the possible excited states are close to the neutron separation energy and taking into account the coupling to the continuum may make some of the states bound even if the shell model predicts them to be unbound.

To clarify the situation, we have performed two experiments. In the first experiment γ spectra were collected from fragmentations of a ^{36}S beam on a thin ^{9}Be target leading to 7500 ^{23}O nuclei. In the second one projectile like fragments of ^{25,26}Ne, ^{27,28}Na, ^{29,30}Mg produced by the fragmentation of a high intensity ^{36}S beam on a thick ^{12}C target were applied as a mixed radioactive beam to be fragmented on an other ^{12}C target. In the second experiment 20000 ^{23}O and 1600 ^{24}O nuclei were produced. 74 BaF_2 detectors were applied to collect the γ-rays in coincidence with the fragments detected through the SPEG spectrometer.

The spectrum of ^{23}O is shown in Fig. 1 in comparison with the spectrum of ^{22}O obtained for the same number of nuclei identified. It can be seen that assuming similar population ratio for the excited states in ^{22}O and ^{23}O the presence of a bound excited state in ^{23}O can be excluded. Applying a GEANT simulation both for ^{23}O and ^{24}O, it can be shown that the fluctuation of the background allows only for a peak in the region of interest which has a population ratio about a factor of 20 smaller than it was observed in other nuclei. Only gamma rays with energy less than of ~700 keV are allowed, which may have some sense in ^{23}O, although it would contradict to all the predictions deduced from experimental systematics.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France

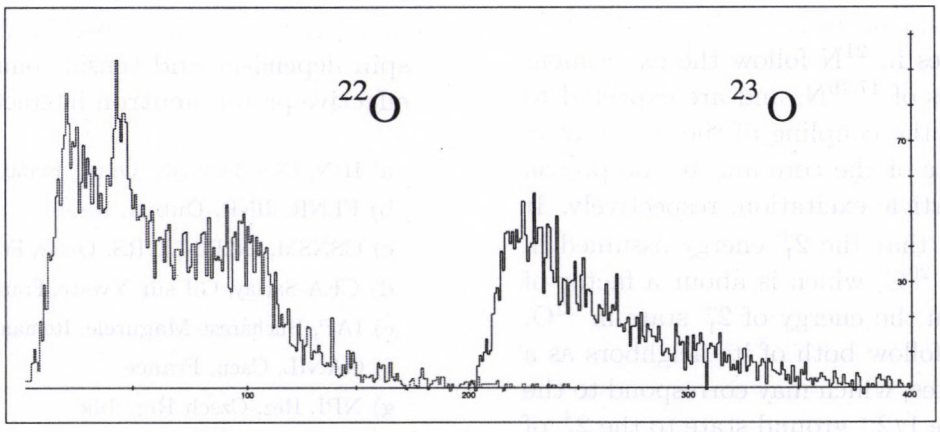

Figure 1. Gamma spectrum of ^{23}O in comparison with that of ^{22}O obtained for the same amount of identified nuclei from fragmentation of ^{36}S beam on a ^{9}Be target.

2.12 Band structure in ^{43,45}Cl: simultaneous break down of the Z=16 and N=28 subshells

Zs. Dombrádi, D. Sohler, J. Timár, F. Azaiez[a], O. Sorlin[a], F. Amorini[a], D. Baiborodin[b], A. Bauchet[c], F. Becker[d], M. Belleguic[a], C. Borcea[e], C. Bourgeois[a], Z. Dlouhy[g], C. Donzaud[a], J. Duprat[a], D. Guillemaud-Mueller[a], F. Ibrahim[a], M.J. Lopez[f], R. Lucas[h], S.M. Lukyanov[b], V. Maslov[b], J. Mrazek[g], C. Moore[i], Yu.-E. Penionzhkevich[b], L. Petizon[a], M.G. Saint-Laurent[f], F. Sarazin[c], J.A. Scarpaci[a], M. Stanoiu[f], G. Sletten[j], C. Stodel[a], M. Taylor[i], C. Theisen[d], G. Voltolini[f]

The particle core coupling is a sensitive test of the quadrupole properties of the core. Thus, analysing the level scheme of an odd nucleus one can deduce conclusions on the rigidity against quadrupole deformation of the core.

The energy systematics of the odd Cl nuclei is shown in Fig. 1. As it is seen in the figure, in addition to the $d_{3/2}$ ground state, $s_{1/2}$ single particle state is available below 3 MeV in ^{37}Cl. This is in agreement with the fact that its core, the ^{36}S nucleus lies at the crossing of the N=20 and Z=16 subshell closures, and behaves like a doubly closed shell nucleus. Adding neutrons onto the $f_{7/2}$ orbit the energy difference between these two states is gradually decreasing. A recent experiment using deep inelastic reaction suggests that their order is changed up already at N=24. To follow the single particle energy systematics, and to test the rigidity of the N=28 shell closure we have investigated the structure of the ^{43,45}Cl isotopes.

In the experiment a $^{48}Ca^{20+}$ beam of 60.3 MeV·A energy and 15 enA intensity was fragmented on a ^{9}Be target of 2.76 mg/cm^2 thickness. The emerging fragments were identified by use of the SPEG magnetic spectrometer. The γ rays emitted in flight by the excited fragments were detected by 74 BaF_2 and 3 segmented Ge clover detectors.

The proposed level schemes for the ^{43,45}Cl nuclei (Fig. 1) were obatined on the basis of the γ and $\gamma\gamma$ spectra. They give confidence on lowering of the $1/2^+$ state, and show a clear band structure for both isotopes. Development of a band like structure in ^{45}Cl contradicts to the rigidity of the core and represents an other evidence for break down of the N=28 shell closure.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France
i) OLL, Univ. of Liverpool, Liverpool, UK
j) NBI, Copenhagen, Denmark

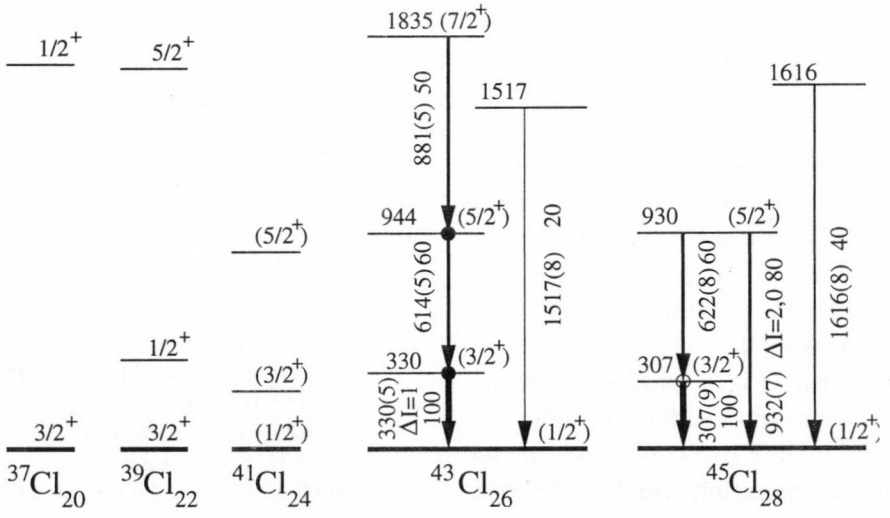

Figure 1. Systematics of the excited states of the neutron rich chlorine isotopes.

2.13 Observation of a *ns* isomeric state in ^{45}Ar: how the break up of the N=28 shell takes place

Zs. Dombrádi, D. Sohler, J. Timár, Z. Elekes, F. Azaiez[a], O. Sorlin[a], F. Amorini[a], D. Baiborodin[b], A. Bauchet[c], F. Becker[d], M. Belleguic[a], C. Borcea[e], C. Bourgeois[a], Z. Dlouhy[g], C. Donzaud[a], J. Duprat[a], D. Guillemaud-Mueller[a], F. Ibrahim[a], M.J. Lopez[f], R. Lucas[h], S.M. Lukyanov[b], V. Maslov[b], J. Mrazek[g], C. Moore[i], Yu.-E. Penionzhkevich[b], L. Petizon[a], M.G. Saint-Laurent[f], F. Sarazin[c], J.A. Scarpaci[a], M. Stanoiu[f], G. Sletten[j], C. Stodel[a], M. Taylor[i], C. Theisen[d], G. Voltolini[f]

Strength of the N=28 shell closure at Z=18 has been investigated by in-beam γ-spectroscopic study of the $^{45,46}_{18}\mathrm{Ar}_{27,28}$ nuclei.

In the experiment a $^{48}\mathrm{Ca}^{20+}$ beam of 60.3 MeV·A energy and 15 enA intensity was fragmented on a ^{9}Be target of 2.76 mg/cm^2 thickness. The emerging fragments were detected by the SPEG magnetic spectrometer. $\sim$1.1·10^5 ^{45}Ar and $\sim$2.7·10^5 ^{46}Ar nuclei were produced during the experiment. The γ rays emitted in flight by the excited fragments were detected by 74 BaF_2 and 3 segmented Ge clover detectors. The BaF_2 crystals were mounted symmetrically above and below the target at a mean distance of 16 cm covering $\sim$80% of the total solid angle. The 3 segmented Ge clover detectors were placed at about 15 cm far from the target at the angles of 85°, 122° and 136° with respect to the beam direction. The γ-ray spectra obtained were corrected for the Doppler-shift caused by the large fragment velocity ($v/c = 0.34$).

Angular distributions of the intensities of the γ rays were used to deduce their multipolarities. Analysing the angular distribution of the 542 keV transition in ^{45}Ar it was found that the width of the peak is about twice as large at 85° than at 135°. Performing a GEANT simulation by assuming different life times, the increased width at a more forward direction could be interpreted as a consequence of a finite life time of the emitting state. The experimental width ratio is compared with the simulated values in Fig. 1.

It can be seen from Fig. 1. that experimental width ratio measured at different angles results in a $0.34^{+0.32}_{-0.15}$ ns half live corresponding to a single particle E2 transition. Such a life time is expected from large scale shell calculations for the intruder $3/2^-$ state. This means that already the first excited state in ^{45}Ar arises from an intruder configuration. The lowering of the $3/2^-$ state from ^{47}Ca to ^{43}S is much faster than the lowering of the $p_{3/2}$ single particle state may be. Thus, this sudden fall of the energy of the $3/2^-$ state shows that the breaking of the N=28 shell takes place similarly to the case of the N=20 shell by sinking of the intruder states below the normal ones.

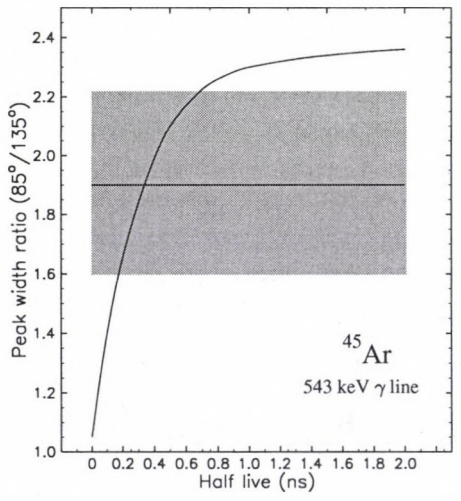

Figure 1. Comparison of the peak width ratio obtained for the 542 keV transition of ^{45}Ar (horizontal line with the hatched zone representing its uncertainty) with GEANT simulation.

a) IPN, IN2P3-CNRS, Orsay, France
b) FLNR, JINR, Dubna, Russia
c) CSNSM, IN2P3-CNRS, Orsay, France
d) CEA-Saclay, Gif sur Yvette, France
e) IAP, Bucharest-Magurele, Romania
f) GANIL, Caen, France
g) NPI, Rez, Czech Republic
h) IPN, Lyon, France
i) OLL, Univ. of Liverpool, Liverpool, UK
j) NBI, Copenhagen, Denmark

2.14 Maximally aligned states in ^{99}Ag

D. Sohler, Zs. Dombrádi, J. Blomqvist[a], J. Cederkäll[a,b], J. Huijnen[c], M. Lipoglavšek[d], M. Palacz[e], A. Ataç[f], C. Fahlander[g], H. Grawe[h], A. Johnson[a], A. Kerek[a], W. Klamra[a], J. Kownacki[e], A. Likar[d], L-O. Norlin[a], J. Nyberg[f], J. Persson[f], D. Seweryniak[i], G. de Angelis[j], P. Bednarczyk[j,k,l], D. Foltescu[m], D. Jerrestam[n], S. Juutinen[o], E. Mäkelä[o], M. de Poli[j], H. A. Roth[m], T. Shizuma[p], Ö. Skeppstedt[m], G. Sletten[p], J. Timár, S. Törmänen[p], M. Weiszflog[f]

Excited states of ^{99}Ag were populated via the ^{50}Cr + ^{58}Ni (261 MeV) reaction using the NORDBALL detector array equipped with charged-particle and neutron detector systems for reaction channel separation. On the basis of the measured $\gamma\gamma$-coincidence relations and angular distribution ratios a significantly extended level scheme has been constructed up to E_x ~7.8 MeV and I=35/2.

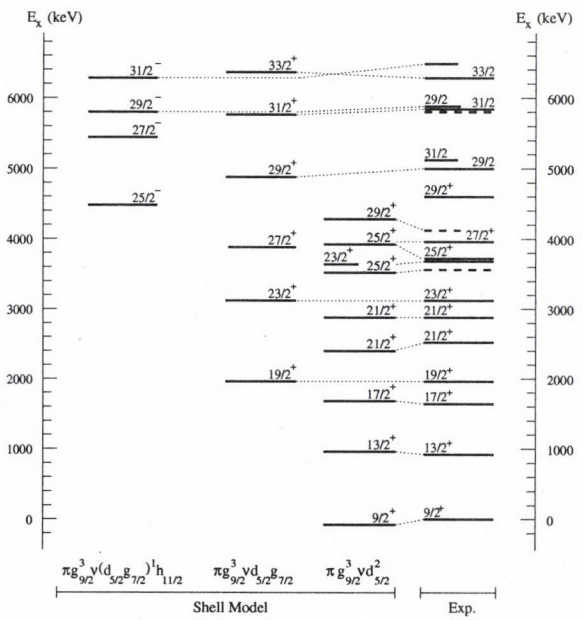

Figure 1. Experimental levels of ^{99}Ag are compared with the theoretical states calculated in the framework of the shell model. The horizontal dashed lines show tentative experimental levels.

The experimental results were interpreted in terms of the shell model. The excited states could be described by angular momentum coupling of three $g_{9/2}$ proton holes with two neutrons in the $g_{7/2}, d_{5/2}, d_{3/2}, s_{1/2}$, and $h_{11/2}$ orbits. The calculated and measured energies are compared in Figure 1. According to the shell model calculations the yrast states up to spin $29/2^+$ are expected to arise mainly from the $\pi g_{9/2}^3 \nu d_{5/2}^2$ configuration, while the second states in this spin region, as well as the yrast states up to $33/2^+$ come from the $\pi g_{9/2}^3 \nu d_{5/2} g_{7/2}$ configuration. All the yrast states up to $33/2^+$ have been found experimentally, in addition some of the yrare states in the $21/2$–$29/2^+$ spin region were identified. The 4109 keV state is a candidate for the fully aligned $\pi g_{9/2}^3 \nu d_{5/2}^2$ state, while the 6265 keV state was assigned to the fully aligned $\pi g_{9/2}^3 \nu d_{5/2}^1 g_{7/2}^1$ configuration.

The results are published in Ref. 1.

a) Royal Institute of Technology, Stockholm, Sweden
b) CERN, Geneva, Switzerland
c) The Svedberg Laboratory, Uppsala, Sweden
d) J. Stefan Institute, Ljubljana, Slovenia
e) Heavy Ion Laboratory, Warsaw, Poland
f) Uppsala University, Uppsala, Sweden
g) Lund University, Lund, Sweden
h) GSI, Darmstadt, Germany
i) Argonne National Laboratory, Chicago, USA
j) Laboratori Nazionali di Legnaro, Padova, Italy
k) IReS, Strasbourg, France
l) The Niewodniczanski Institute of Nuclear Physics, Krakow,Poland
m) Chalmers University of Technology, Gothenburg, Sweden
n) Uppsala University, Nyköping, Sweden
o) University of Jyväskylä, Jyväskylä, Finland
p) Niels Bohr Institute, Copenhagen, Denmark

[1] D. Sohler *et al.*, accepted in Eur. Phys. Jour. A

2.15 Band terminating states in ^{101}Ag

D. Sohler, J. Timár, Zs. Dombrádi, J. Blomqvist[a)], J. Cederkäll[a,b)], J. Huijnen[c)], M. Lipoglavšek[d)], M. Palacz[e)], A. Ataç[f)], C. Fahlander[g)], H. Grawe[h)], A. Johnson[a)], A. Kerek[a)], W. Klamra[a)], J. Kownacki[e)], A. Likar[d)], L-O. Norlin[a)], J. Nyberg[f)], J. Persson[f)], D. Seweryniak[i)], G. de Angelis[j)], P. Bednarczyk[j,k,l)], D. Foltescu[m)], D. Jerrestam[n)], S. Juutinen[o)], E. Mäkelä[o)], M. de Poli[j)], H.A. Roth[m)], T. Shizuma[p)], Ö. Skeppstedt[m)], G. Sletten[p)], S. Törmänen[p)], M. Weiszflog[f)]

The structure of ^{101}Ag was studied populating its excited states in the ^{50}Cr(^{58}Ni,3p1α) reaction. The NORDBALL array equipped with a charged particle ball and neutron scintillators was used to detect the evaporated particles and γ rays. The level scheme of ^{101}Ag was constructed on the basis of $\gamma\gamma$−coincidence relations and new high spin states were established up to 10.7 MeV excitation energy. The high-spin parts of the observed bands were compared with Configuration-constrained cranked Nilsson-Strutinsky calculations. A good agreement have been found between the calculations and the experimental observations:

a) the negative-parity high-spin band, containing one The experimental $h_{11/2}$ neutron, is lower in energy than the positive-parity band containing two $h_{11/2}$ neutrons.

b) the spins of the experimental states lying at the highest energy agree well with the spins obtained from the calculations for the terminating non-collective oblate states.

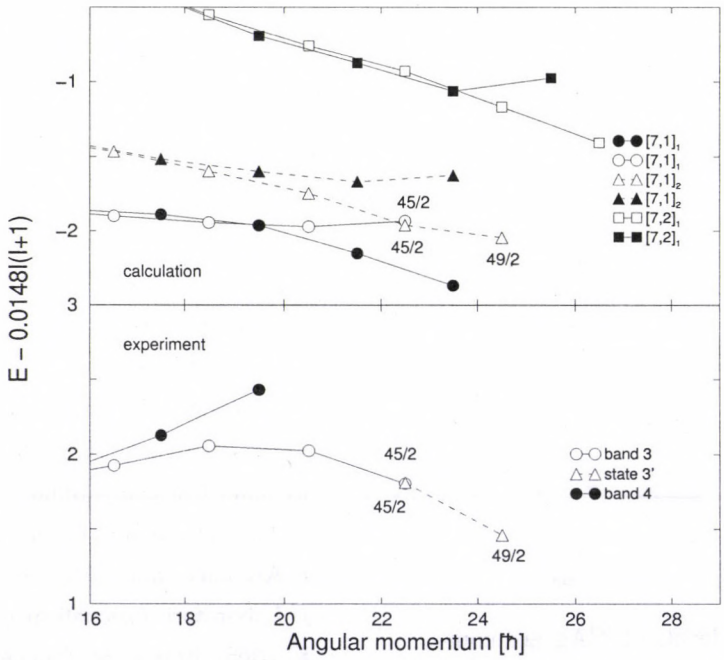

Figure 1. Excitation energy relative to a rigid rotor reference as a function of the spin for the calculated (top) and experimental (bottom) bands.

a) Royal Institute of Technology, Stockholm, Sweden
b) CERN, Geneva, Switzerland
c) The Svedberg Laboratory, Uppsala, Sweden
d) J. Stefan Institute, Ljubljana, Slovenia
e) Heavy Ion Laboratory, Warsaw, Poland
f) Uppsala University, Uppsala, Sweden
g) Lund University, Lund, Sweden
h) GSI, Darmstadt, Germany
i) Argonne National Laboratory, Chicago, USA
j) Laboratori Nazionali di Legnaro, Padova, Italy
k) IReS, Strasbourg, France
l) The Niew. Inst. of Nucl. Phys., Krakow,Poland
m) Chalmers Univ. of Tech., Gothenburg, Sweden
n) Uppsala University, Nyköping, Sweden
o) University of Jyväskylä, Jyväskylä, Finland
p) Niels Bohr Institute, Copenhagen, Denmark

2.16 Experimental study of neutron-skin thicknesses in neutron-rich isotopes

A. Krasznahorkay, P. Adrich[a)], T. Aumann[a)], M. Csatlós, U. Datta Pramanik[a)], H. Emling[a)], J. Gulyás, C. Nociforo[a)], P. Rudrajyoti[a)], H. Simon[a)], D. Sohler, K. Jones[a)], H. Wörtche[b)]

The difference between the neutron and proton radii of a heavy stable nucleus is of the order of a few percent. This feature of nuclei, which is essentially a neutron skin, may provide fundamental nuclear structure information. By measuring precisely the thickness of the neutron skin one may constrain the symmetry energy term of the nuclear energy functional [1].

The precise knowledge of the symmetry energy is essential not only for describing the structure of neutron-rich nuclei, but also for describing the properties of the neutron-rich matter in nuclear astrophysics [2] and for determining the neutron densities for atomic parity-nonconserving (PNC) experiments, which may provide the most precise test of the Standard Model at low energy.

We have introduced recently a new tool for studying the neutron-skin thickness, by exciting the spin-dipole resonance (SDR) [3]. It has been proved that the total L=1 strength of the SDR is sensitive to the neutron-skin thickness. This resonance can be strongly excited in (p,n) reaction using radioactive beams so we have proposed to study the neutron-skin thicknesses in a wide range of isotopes by measuring the strength of the spin-dipole resonance excited in (p,n) reactions using inverse kinematics.

As a first step of the project we used ^{124}Sn stable beam at GSI Darmstadt with an energy of 400 AMeV, in order to check the experimental setup and the background conditions.

The main background in the usual (p,n) reactions at high excitation energy (Ex $\geq$ 20 MeV) is caused by the quasi free charge exchange process on the target neutrons. In this process protons also leave the target producing a different final nucleus compared to the normal charge-exchange process. In the inverse reaction in which we can clearly identify the final nucleus as well, this type of background can substantially be reduced.

The identification and momentum analysis of heavy reaction products emerging in the collision with a CH_2 target have been performed using position sensitive Si diodes placed between the target and a large dipole magnet (ALADIN), and using scintillating fiber arrays and a time-of-flight wall (1.8 x 1.4 m^2) consisting of 64 position sensitive organic scintillator paddles.

The excitation energy of the SDR have been determined by summing up the the energies of their decay products. The determination of the energies of the neutrons and γ-rays have been performed by using a large (2 x 2 x 1 m^3) neutron detector (LAND) and the 162 NaI(Tl) detectors of the crystal ball (CB), respectively.

The detection of the recoiled neutrons from the (p,n) reaction, performed by means of the CB as well. The discrimination between the neutrons and γ-rays was performed by the time of flight method. The CB has $\epsilon > 85$ % efficiency for such low-energy ($E_n \leq 4$ MeV) neutrons. We are going to combine the excitation energy information with the angular information for detecting the neutrons in order to enhance the L=1 SDR strength.

a) GSI, Darmstadt, Germany.

b) KVI, Groningen, The Netherlands.

[1] R.J. Furnstahl, Nucl. Phys. A706 (2002) 85.

[2] C.J. Horowitz and J. Piekarewicz, Phys. Rev. Lett. 86 (2001) 5647.

[3] A. Krasznahorkay et al., Phys. Rev. Lett. 82 (1999) 3216; AIP Conf. Proc. 610 (2002) 751.

2.17 Experimental evidence for signature inversion in ^{132}La from a revisited level scheme

J. Timár, D. Sohler, B.M. Nyakó, L. Zolnai, Zs. Dombrádi, E. S. Paul[a], A.J. Boston[a], C. Fox[a], P.J. Nolan[a], J.A. Sampson[a], H.C. Scraggs[a], A. Walker[a], J. Gizon[b], A. Gizon[b], D. Bazzacco[c], S. Lunardi[c], C.M. Petrache[c,d], A. Astier[e], N. Buforn[e], P. Bednarczyk[f], N. Kintz[f]

The decay out of the $\pi h_{11/2}\nu h_{11/2}$ band to the known low-energy levels in ^{132}La was studied using the ^{100}Mo(^{36}S,$p3n$) reaction at a bombarding energy of 160 MeV. γ rays were detected by the EUROBALL IV spectrometer. The level scheme of ^{132}La has been deduced using $E_{\gamma 1} - E_{\gamma 2} - E_{\gamma 3}$ triples events which were sorted into RADWARE cubes. In order to obtain information on the γ-ray multipolarities, angular correlation information has been extracted from the coincidence data. The linear polarization of the strongest γ-rays were also measured using the 24 clover detectors as Compton polarimeters.

The low-energy part of the ^{132}La level scheme obtained from the present experiment is shown in Fig. 1. The intermediate structure connecting the $\pi h_{11/2}\nu h_{11/2}$ band to the 6^- isomeric state in ^{132}La has been further developed. A new level has been added to the top of this intermediate structure. Unambiguous spins and parities have been derived for these levels on the basis of obtained experimental angular intensity ratios and linear polarization data. These experimental results enabled us to assign definite spins and tentative parity to the levels in the $\pi h_{11/2}\nu h_{11/2}$ band. Due to the addition of the new level the obtained spins in the band are higher by one unit than the former, tentative experimental values.

These new spins agree well with those proposed for ^{132}La from the energy systematics of the levels in the $\pi h_{11/2}\nu h_{11/2}$ bands of the A≈130 odd-odd La isotopes. This agreement gives further support to the proposed spin assignment derived from level-energy systematics for the $\pi h_{11/2}\nu h_{11/2}$ bands in the neighbouring odd-odd La isotopes. Using the new spin values we obtain inverted signature splitting for this band in ^{132}La at low spins, giving experimental evidence for the existence of signature inversion in this nucleus.

The results are published in Ref. 1.

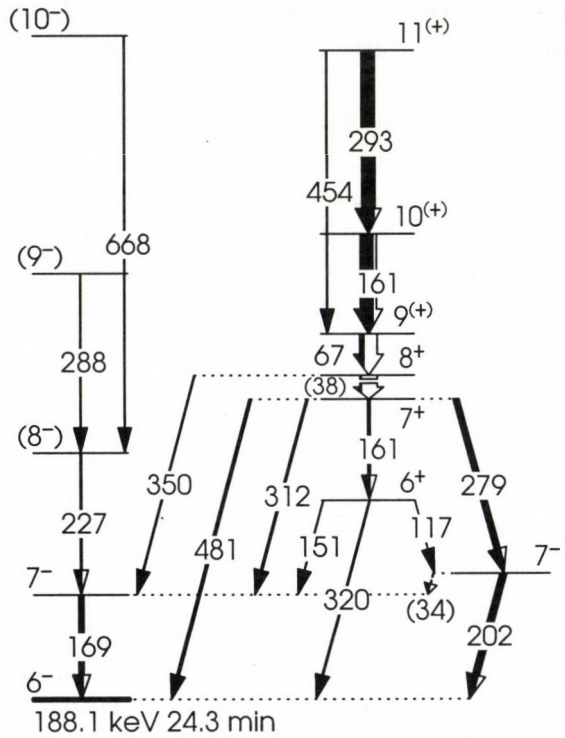

Figure 1. Low-energy level scheme of ^{132}La obtained in the present work. γ-ray energies are given in keV. The width of the arrows is proportional to the transition intensities. Dashed arrows with energy labels in parenthesis indicate tentative transitions.

a) OLL, Univ. of Liverpool, Liverpool, United Kingdom

b) IN2P3-CNRS, Grenoble, France

c) Dip. di Fis. and INFN, Padova, Italy

d) University of Camerino, Camerino, Italy

e) IPN Lyon, IN2P3-CNRS, Villeurbanne, France

f) IReS, Strasbourg, France

[1] J. Timár *et al.*, Eur. Phys. Jour. A 16 (2003) 1.

2.18 The Gamow-Teller resonance in the rare-earth region

E. Nácher[a)], B. Rubio[a)], A. Algora[a,b)], D. Cano-Ott[a)], J.L. Tain[a)], A. Gadea[a,c)], P. Kleinheinz[a)], L. Batist[d)], J. Döring[d)], R. Kirchner[d)], I. Mukha[d)], E. Roeckl[d)], C. Plettner[d)], M. Gierlik[d)]

The nuclei around ^{146}Gd in the rare-earth region represent the unique case in the nuclide chart where the Gamow-Teller (GT) transition $\pi h_{11/2} \rightarrow \nu h_{9/2}$ is accesible in β-decay. Among these nuclei, the odd-odd N=83 cases are of special interest for different reasons. The three nuclei considered here have two β-decaying isomers with spins 2^- and 9^+. These six cases allow us to study the B_{GT} as a function of the number of $\pi h_{11/2}$ particles present in the parent nucleus. A second reason for studying these particular nuclei is the fact that in all cases the 2^- isomer can be produced cleanly, without contamination from the 9^+ one.

Different experiments were carried out at GSI with the aim of a systematic study of the β-decay of the nuclei described above. In these experiments the On-Line Mass-Separator was used to provide a clean radioactive source of the isotope of interest. The β-decay of each case was studied using a Total Absorption Spectrometer, a special device to detect entire gamma cascades rather than individual gamma-rays. This has proved to be the best tool to extract the real B_{GT} of the decay [1].

In fig. 1 we present the B_{GT} distribution for the six cases studied in this work. Each of them represents a different occupancy number of the $\pi h_{11/2}$ orbital starting with 0 protons (^{148}Tb 2^-) and finishing with 5 protons (^{152}Tm 9^+). The decay of ^{148}Tb and ^{150}Ho were presented in [2], and the decay of ^{152}Tm is presented here for the first time. In the low spin cases the B_{GT} is concentrated in a very narrow prominent peak at about 4.5 MeV, the GT resonance. This kind of decay is produced when a proton pair in the $h_{11/2}$ orbital is broken, and one of the protons decays populating four quasi-particle (4qp) states in the daughter nucleus. On the other hand, the decay of the high-spin cases have two different components: the decay of the paired particle as in the former case, and the decay of the unpaired $\pi h_{11/2}$ proton that can populate only one single 2qp state in the daughter nucleus. It is important to theoretically quantify the observed ratio between the B_{GT} going to the 2qp state and the B_{GT} going to the 4qp state, and its evolution with the number of protons in the $h_{11/2}$ orbital.

a) IFIC, Valencia

b) MTA ATOMKI, Debrecen

c) LNL, Legnaro

d) GSI, Darmstadt

e) University of Warsaw

[1] D. Cano Ott PhD Thesis. Univ. de Valencia 2000.

[2] E. Nácher *et al.* GSI Annual Report 2001.

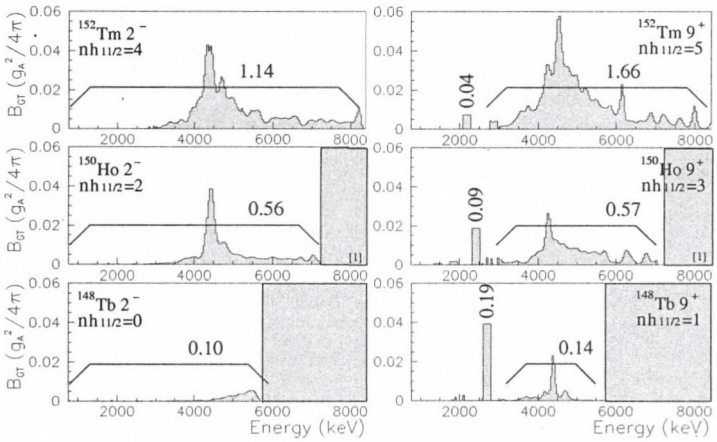

Figure 1. Gamow-Teller strength distribution observed in the decay of the different cases of interest. The numbers in the graphs represent the integrated B_{GT} in $g_A^2/4\pi$ units.

2.19 Enhanced α-decay of the highly deformed states excited in the ^{235}U(d,pf) reaction

A. Krasznahorkay, M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, A. Krasznahorkay Jr., H.J. Maier[a], *Z. Máté, D. Sohler, P.G. Thirolf*[a], *J. Timár*

In a program aiming at studying highly deformed states in the actinides we have successfully used the resonance tunneling method for identifying super- and hyperdeformed rotational bands [1]. Another possible signature of these highly deformed states can be their enhanced α-decay. The idea is that the deformation of the Coulomb field at the tips of an elongated shape lowers the Coulomb barrier and in this way enhances the tunneling probability for charged particles. Assuming super- and hyperdeformed shapes, the α-decay probability can be enhanced by 3 - 5 orders of magnitude [2].

The α-decay of the highly deformed states excited in the ^{235}U(d,pf) reaction was explored in Debrecen using the 103 cm isochronous cyclotron. The contribution of the deuteron-induced prompt fission was minimized by choosing a very low (8 MeV) bombarding energy. We used enriched (99.89 %) ^{235}U targets with a thickness of 100 μg/cm^2. The protons were identified with a ΔE(100 μm) - E(3 mm) silicon particle telescope placed at 135° with respect to the beam direction and having a relatively large (125 msr) solid angle. The α-particles were measured in coincidence with the protons using three large area (12 cm^2) and thin (100 μm) silicon detectors placed at 135° with respect to the beam direction and having a total solid angle of 10 % of 4π. The scattered deuterons and the high energy α-particles, originating from ternary fission punched through the detector giving no background in our region of interest ($8 \leq E_\alpha \leq 12$ MeV). The fission fragments, however, deposited their full energy in the detectors, and hence did not disturb the experiment either. By knowing the fission probability of these highly excited states, we could make a good comparison for calculating the probability of the α-decay.

We have observed only a weak (10^{-3}) α-decay branching ratio compared to fission. From the energy of the α-particles and from the excitation energy of the ^{236}U nucleus, the final state spectrum in ^{232}Th has been calculated for each event. Surprisingly, we have observed α-decay to states lying at about 1 MeV and also to some higher-lying states, but nothing to the ground state.

The partial half-life of the α-decay has been estimated from the measured branching ratio and from the total widths of the resonances measured in the ^{235}U(n,f) reaction and has been compared to the prediction of the Geiger-Nuttal rule. Significant enhancement ($\sim 10^3$) of the α-decay was observed proving that we excited highly deformed states.

a) Sektion Physik, Universität München, Garching, Germany.

[1] A. Krasznahorkay et al., Phys. Rev. Lett. 80 (1998) 2073; Phys. Lett. B461 (1999) 15; M. Hunyadi et al., Phys. Lett. B505 (2001) 27.

[2] A. Marinov et al., APH N.S. Heavy Ion Physics, 13 (2001) 133 and references therein.

2.20 Resonant tunneling through the 2^{nd} and 3^{rd} minimum in ^{236}U

M. Csatlós, A. Krasznahorkay, Y. Eisermann[a], T. Faestermann[b], G. Graw[a], J. Gulyás, D. Habs[a], M.N. Harakeh[c], R. Hertenberger[a], H.J. Maier[a], Z. Máté, O. Schaile[a], P.G. Thirolf[a] and H.F. Wirth[a]

One of the characteristic features of the HD states in the actinide region is the large moment of inertia. Using the resonance tunneling through the fission barrier we have been studying HD states in U isotopes for several years now [1],[2].

The aim of our latest experiment was to increase the energy resolution we used before to observe the fission resonances in ^{236}U and resolve the structure of the vibrational resonances in the third minimum as well as to study the mass distribution from the decay of those resonances.

In order to investigate these resonances, we measured proton-fission fragment coincidences in (d,pf) reactions. The experiment was performed at the Munich Tandem accelerator using a 9.75 MeV deuteron beam and enriched (99.89 %) ^{235}U targets with a thickness of 100 $\mu g/cm^2$.

The experimental arrangement was similar to the one described in Ref. [1], but the energy resolution was considerably improved (FWHM ~8 keV) compared to our previous data (FWHM ~20 keV) [2].

The investigated excitation energy region was: $4.9 < E^* < 5.6$ MeV. The resonances at 5.25, 5.35 and 5.47 MeV had been identified as hyperdeformed resonances [2], but without resolving any rotational structure, which now could be achieved (see in Fig. 1). The lower part of the spectrum which is close to the inner barrier of the second well ($4.9 < E^* < 5.2$ MeV) was analysed separately.

Assuming overlapping rotational bands with the same moment of inertia and intensity ratio for the members in a band, we fitted the upper part of the spectrum using simple Gaussians for describing the different band members in the same way as we did it previously [1],[2]. We deduced a rotational parameter of $R = \hbar^2/2\theta = 2.3 \pm 0.4$ keV and a moment of inertia of $\Theta = 217 \pm 38\ \hbar^2/MeV$ from the data.

The moments of inertia obtained previously for the HD states in ^{234}U and ^{232}Th are $227 \pm 21\ \hbar^2/MeV$ [1] and $183 \pm 7\ \hbar^2/MeV$ [3]. These values agree nicely with the values calculated by Shneidman et al., who assumed dinuclear systems, suggesting the possibility of an exotic heavy clustering as predicted also by Ćwiok et al., [5,6].

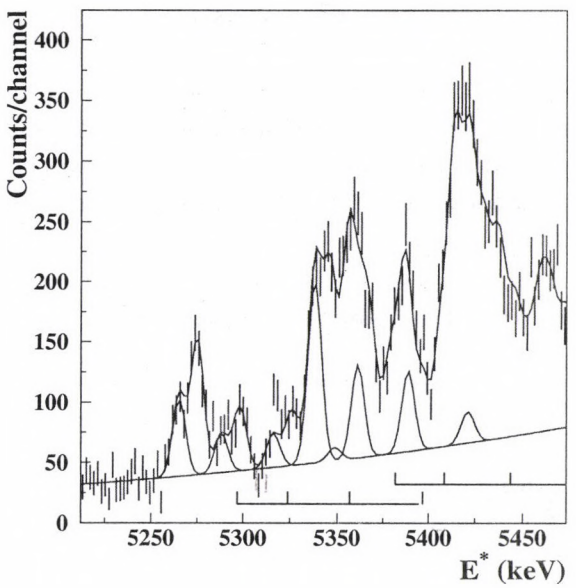

Figure 1. Part of the measured proton spectrum from the ^{236}U(d,pf) reaction fitted with 11 rotational bands with a common rotational parameter. The pattern of a rotational band is also shown as full line and marked by vertical lines.

The depth of the third well has also been determined by comparing the experimentally obtained average level distances of the rotational (J=4) band heads with the calculated ones using the back-shifted Fermi-gas description with parameters determined by Rauscher et al. [4] in a similar way as we did in our previous work on ^{234}U [1]. The result of the comparison is shown in Fig. 2.

We obtained a value of $3.15^{+0.3}_{-0.25}$ MeV for

the energy of the ground state in the third well in perfect agreement with our previous data obtained for ^{234}U, and also in a fair agreement with the theoretical results [5],[6].

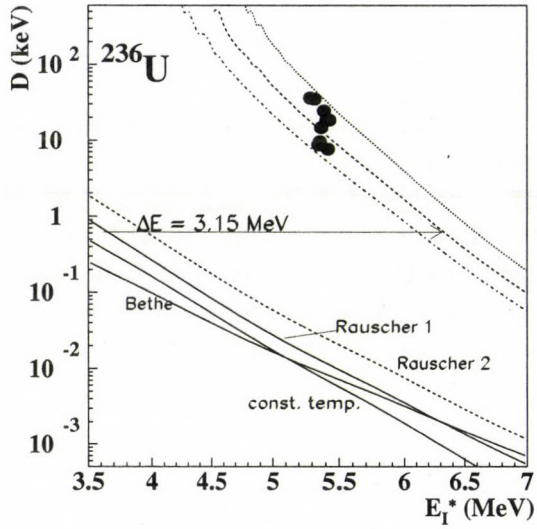

Figure 2. Average distances of the $J = 4$ levels as function of the excitation energy. The solid curves show calculated values by different formulas (see text for details), the dots correspond to experimental values.

The lower excitation energy region, close to the top of the inner barrier is shown in Fig. 3.

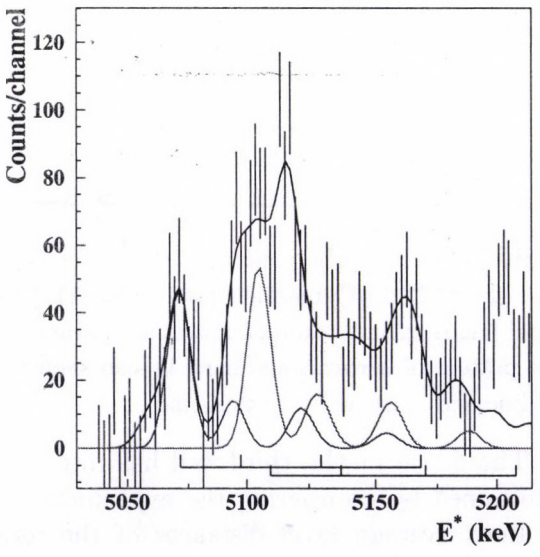

Figure 3. The part of the proton spectrum measured in coincidence with the fission fragments at the lower excitation energy, close to the top of the first barrier. The full curve is the result of the fit. A few members of the rotational bands are also shown and marked by vertical lines.

The observed resonance around 5.1 MeV, was identified by Goldstone et al. [7] as a highly damped superdeformed vibrational resonance. The widths of the peaks in this region are much broader (~15 keV) than in the higher excitation energy region (~8 keV).

Taking this into account, we fitted this part of the spectrum in a similar way as we did in the case of the higher lying resonances. We deduced a rotational parameter R=$2.4^{+0.6}_{-0.4}$ keV, which corresponds to a hyperdeformed configuration. Fission decay of superdeformed states in the second minimum will, in the presence of a third minimum, need the help of hyperdeformed doorway states in the third well. Since the inner barrier is rather thin, a dominant observation of hyperdeformed structures also in the lower excitation energy region around 5.1 MeV can be understood.

In order to study the possible effects of such a dinuclear system on the decay of the HD states, the mass distribution was determined (using the time-difference method) for different excitation-energy regions, but no significant effect was observed.

a) LMU, München, Germany.

b) TU, München, Germany.

c) KVI, Groningen, Germany.

[1] A. Krasznahorkay et al., Phys. Lett. B461 (1999) 15.

[2] A. Krasznahorkay et al., Phys. Rev. Lett. 80 (1998) 2073.

[3] J. Blons et al., Phys. Rev. Lett. 35 (1975) 1749.

[4] T. Rauscher et al., Phys. Rev. C56 (1997) 1613.

[5] S. Ćwiok et al. Phys. Lett. B322 (1994) 304.

[6] T.M. Shneidman et al., Nucl. Phys. A671 (2000) 119.

[7] P.D. Goldstone et al., Phys. Rev. C18 (1978) 1706.

2.21 Search for tri-nuclear states in ^{252}Cf

A. Krasznahorkay, M. Csatlós, Z. Gácsi, J. Gulyás, M. Mutterer[a)]

The formation of clusters is a fundamental aspect of nuclear many body dynamics, as clusters easily form and dissolve without effecting the binding energy. The predicted variety of exotic nuclear shapes, cold fission, and even cold multifragmentation [1] represent big challenges for the contemporary experimental investigations.

An interesting feature of the ^{10}Be accompanied cold fission of ^{252}Cf has been observed [2-4]. The 3.368 MeV gamma line of ^{10}Be, which has a lifetime of 125 fs has been observed as a sharp line without Doppler broadening as it should be if emitted when ^{10}Be is in flight. A possible explanation could be that the ^{10}Be nucleaus is still trapped in a potential well of nuclear molecular character, when the gamma ray emission takes place [1]. Fission energy surface calculations predicts also the existence of a (short lived) quasi-molecular state, decaying into three final fragments.

The aim of the present experiment was to measure the internal conversion coefficient of the 3.368 MeV E2 gamma transition of ^{10}Be in ternary fission of ^{252}Cf. If the internal conversion takes place in a quasi-molecular state, then the electron shell of ^{252}Cf should be taken into account, which gives a relatively large internal conversion coefficient of $\alpha_{tot.} \approx 10^{-2}$. When ^{10}Be gamma transition is emitted in flight we should take into account only their electron shell, which gives a conversion coefficient of $\alpha_{tot.} = 10^{-7}$. The five order of magnitude difference of the two cases may supply a real signature for the quasi-molecular state if it exists.

The experiment was carried out in ATOMKI using a 10 μCi ^{252}Cf source mounted on a thick backing. The ternary particles were identified with a ΔE(10 μm) - E(100 μm) silicon particle telescope placed very close to the source to obtain about 25 % solid angle of 4π. A 6.8 mg/cm2 Al absorber was used before the telescope to shield the detectors from the fission fragments and from the 6.118 MeV alpha-particles of ^{252}Cf. Conversion electrons were detected by a 10 mm thick and 20 cm^2 Ge planar detector in coincidence with the telescope. Because of the thick backing of the source the electron detector should be mounted on the same side of the source where the ΔE - E detector telescope was positioned, so the electrons should go through the telescope, which caused a line broadening of $\approx$20 keV for the 3.368 MeV transition.

During a one-month run we have unambigously identified about 3000 ^{10}Be events with the ΔE - E telescope but no conversion electron line could be observed in the electron spectrum at the 3.368 MeV transition energy. According to the observed very low background we are expecting a peak to background of about 3 : 1. Stronger source and/or longer collection time is needed to draw definite conclusion about these exotic nuclear states.

a) Technische Universität Darmstadt, Darmstadt, Germany.

[1] W. Greiner, APH N.S. Heavy Ion Phys. 13 (2001) 61.

[2] P. Singer, Thesis, Darmstadt (1996), unpublished

[3] J.H. Hamilton, A.V. Ramayya et al., J. Phys. G 20 (1994) L85.

[4] A.V. Ramayya et al., Phys. Rev. Lett. 81 (1998) 947.

2.22 Two particle resonances in Gamow shell model

R. Id Betan[a,b], *R.J. Liotta*[a], *N. Sandulescu*[a,c] *and T. Vertse*

More than three decades ago Berggren introduced a complete system of single particle basis functions (Berggren repesentation) composed of bound states, complex energy resonant sates (Gamow states) and a complex continuum of scattering states along a complex contour [1]. However the first two attempts to use the full Berggren representation for the shell model desciption of many body resonances has been done very recently [2]. The shell model however had to be generalized in order to use the Berggren representation and this new version of the model is the *Gamow shell model.*

In this work [3] two particles outside a closed core are treated in the Gamow shell model. The effect of the core is simulated by a SW potential and a residual interaction of the separable form is used between the particles. The choice of the single particle contour determines the distribution of the complex two particle energies. A major problem is how to distinguish the physical resonances from the spurious states which depend on the shape of the contour and the number of the discetization points. We suggest a method to overcome this difficulty by introducing a contour of rectangular shape with certain parameters. This way an *allowed region* is produced in which the density of the spurious states is low and it is easy to pick up the physical resonances.

We applied the model to study excitations of two neutrons outside a ^{78}Ni core and that of two protons outside a ^{100}Sn core. It is found that although the dominant components in the wave functions of the two particle resonances are based on bound and resonant single particle configurations, the effect of the complex continuum can not be neglected completely if we want to get reasonably good energy value and width for the resonance.

This work was partially supported by the Hungarian OTKA fund Nos. T26244, T29003 and T37991.

a) Royal Institute of Technology, Physics Department Frescati, Frescativagen 24, S-10405, Stockholm, Sweden.

b) Dept. de Fisica, FCEIA, UNR, Av. Pellegrini 250, 2000, Rosario, Argentina.

c) Royal Inst. of Phys. and Nucl. Eng., P. O. Box MG-6, Bucharest-Magurele, Romania.

[1] T. Berggren, Nucl. Phys. A **109**, 265 (1968).

[2] R. Id Betan, R.J. Liotta, N. Sandulescu and T. Vertse, Phys. Rev. Lett. **89**, 042501 (2002) and N. Michel, W. Nazarewicz, M. Ploszajczak and K. Bennaceur, Phys. Rev. Lett. **89**, 042502 (2002).

[3] R. Id Betan, R.J. Liotta, N. Sandulescu and T. Vertse, Phys. Rev. **C**, in press

2.23 Search for low-lying opposite parity states from a simple perspective

L. Hernández de la Peña[a)], *P. O. Hess*[a)], *G. Lévai*

The low-lying spectrum of many light nuclei can be described reasonably well by assigning SU(3) quantum numbers to the states. This validity of the SU(3) symmetry is related to the success of the Elliott model [1], which is a simplified version of the shell model and was designed to describe deformed nuclei up to the sd-shell. The most characteristic term in the Elliott model is the quadrupole-quadrupole force, which respects SU(3) symmetry, but obviously, for a more precise description of the nuclei further symmetry conserving and non-conserving terms are also needed.

When one focuses on basic properties of nuclei in a wide mass range, however, simplified models with fewer parameters (and thus with less arbitrary nature) can be useful. In an attempt of this kind we applied systematically in the Helium to Calcium range the Hamiltonian

$$H = \hbar\omega \mathbf{N} - \chi_A \mathbf{C_2}(\lambda, \mu) \ , \qquad (1)$$

where the coupling parameters of the harmonic term $\mathbf{N}$ (with $\mathbf{N}$=0, 1, 2 for the first three shells) and the second-order Casimir operator $\mathbf{C_2}$ (which is dominated by the $Q \cdot Q$ term) depends on the mass number A [2]. Our objective was to investigate the nature and relative position of the lowest-lying positive- and negative-parity states, and in particular, to identify regions where low-lying opposite-parity states can be expected. We were inspired by the success of the systematic application of a similar (somewhat more sophisticated) Hamitonian to the Be isotopes [2]. Then we also found that the extra terms (e.g. L^2, $L{\cdot}S$) contribute to the relative energy of the lowest-lying states only with a minor (up to 0.5 MeV) correction. The simple Hamiltonian (1) essentially describes the competition of the harmonic term and the $Q \cdot Q$ force, which is influenced indirectly also by the Pauli principle via the allowed (λ, μ) SU(3) multiplets in each shell.

We found that the agreement to available experimental data is reasonable, except when the nucleus is near a shell closure and has small deformation. Our investigations predicted a small region with $A = 11$ to 19 where the lowest-lying opposite-parity state is found at an especially low energy in odd-even and odd-odd isotopes. At the neutron-rich side of the isotope chains the nature of the ground state also changed systematically: states from the leading SU(3) multiplet from the $2\hbar\omega$ shell came *below* the leading $0\hbar\omega$ state. This happened typically due to the increased eigenvalue of the $2\hbar\omega$ state, which means also large deformation and strong B(E2) transitions from the excited members of the ground-state band.

These findings are very similar to observations interpreted in terms of a changing shell structure [3]. In our approach we argue that these phenomena can be interpreted in terms of the SU(3) shell model, simply based on the drastic change with neutron number of the (λ, μ) SU(3) representations.

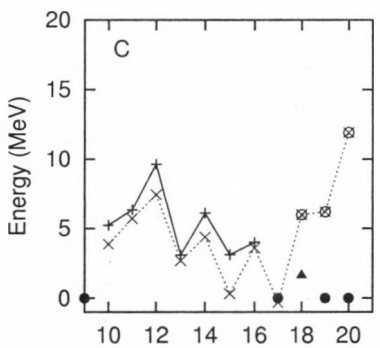

Figure 1. The lowest opposite-parity states in C isotopes. Solid/broken line: Exp./Th.

a) UNAM, México D.F., Mexico

[1] J. P. Elliott, Proc. R. Soc. London, A 245 (1958) 128 and 562.

[2] L. Hernández de la Peña, P. O. Hess, G. Lévai and A. Algora, J. Phys. G 27 (2001) 1.

[3] I. Tanihata, Nucl. Phys. A 682 (2001) 114c and references.

2.24 Perturbative Quantum Chromodynamics

Z. Trócsányi

Strong interaction processes, characterised by a large kinematic scale, are described in perturbative QCD by a fixed-order expansion of the partonic cross section in α_s. In kinematic regions characterised by two very different hard scales, a fixed-order expansion is not sufficient: large logarithms of the ratio of the kinematic scales appear, which have to be resummed. In processes where the centre-of-mass energy s is much larger than the typical momentum transfer t, the sub-process which features gluon exchange in the crossed channel tends to dominate over the other sub-processes. That sub-process constitutes the leading-order term of the BFKL equation, which is an equation for the Green's function of gluon exchanged in the crossed channel and resums the logarithms of type $\ln(s/|t|)$.

Recently several observables, among those $\gamma^*\gamma^* \to$ *hadrons* in e^+e^- collisions, have been proposed as candidates for the detection of the BFKL evolution, and have been measured as functions of observables, which aim to single out large logarithms of type $\ln(s/|t|)$. In Ref. [1] we pointed out that a fixed-order prediction for this process at the NLO accuracy (inclusion of the first radiative corrections) is not sufficient to describe the experimental data taken at LEP at the high-energy end of the hadronic spectrum. However, in order to claim detection of BFKL gluon radiation in a given process, we must also ascertain that (i) the sub-process with gluon exchange in the crossed channel, i. e. the leading order of the BFKL resummation, dominates over all the other sub-processes; (ii) the acceptance cuts of the experiment under consideration allow us to reach the kinematic region of the high-energy limit, where the approximations needed for a BFKL analysis are valid.

In Ref. [2] we considered the contribution of the four-parton final states, which constitute the leading-order of the BFKL resummation to the $\gamma^*\gamma^* \to$ *hadrons* process to check if the two conditions above are fulfilled. In order to explore the footprints of the BFKL resummation we used a variable Y that for large values approaches the ratio of the hadronic energy over a typical momentum transfer (the geometric mean of the photon virtualities), $Y \simeq \ln(W^2/\sqrt{Q_1^2 Q_2^2})$. We have shown that indeed the four-parton final states play an important role in the large-Y region, however they must be evaluated *exactly*. In fact, the high-energy limit, which constitutes the kinematic framework of the BFKL resummation, is not sufficiently accurate at LEP2 energies, when compared to the experimental accuracy. Thus, if a BFKL resummation is used in the large Y region, we expect the subleading logarithmic corrections to be sizeable. We have also shown that the contribution of four-parton final states to the total cross section reduces the discrepancy between the theory and the LEP2 data of the L3 Collaboration (see Fig. 1). However, even allowing for the large scale uncertainty the LEP2 data still lie above the theory.

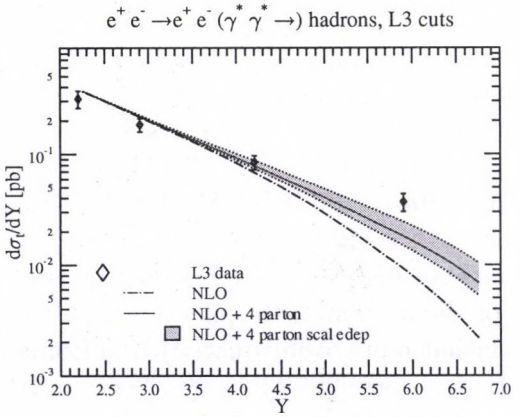

Figure 1. The distribution of the total hadronic cross section as a function of Y, at NLO (dot-dashed line), and at NLO plus the contribution of the four-parton final states (solid line).

[1] M. Cacciari, V. Del Duca, S. Frixione and Z. Trócsányi, JHEP 0102 (2001) 029.

[2] V. Del Duca, F. Maltoni and Z. Trócsányi, JHEP 0205 (2002) 005.

3.1 Laser Spectroscopy of Antiprotonic Helium Atoms

D. Horváth, B. Juhász, E. Takács (ASACUSA collaboration)

In 2002, laser spectroscopy studies of antiprotonic helium atoms ($\overline{p}-e^{-}-He^{++} \equiv \overline{p}He^{+}$) were carried out at the Antiproton Decelerator (AD) of CERN in July and August. The experiments used both the direct AD antiproton beam (energy: 5.3 MeV) and the decelerated beam (energy: 20–120 keV), which were produced using the Radio Frequency Quadrupole Decelerator (RFQD), a unique device which both decelerates and focuses the antiproton beam. Unlike the previous year, this time an S-shaped achromatic spectrometer line was added between the exit of the RFQD and the entrance of our cryostat. This spectrometer line only transports the decelerated antiprotons to the cryostat, while the undecelerated antiprotons (appr. 50% of the beam) annihilate far from the cryostat, thus reducing a major source of background in the annihilation time spectrum.

Another new equipment we started to use was a high-pressure, high-purity target chamber for room temperature measurements. The chamber has one stainless steel window for the antiproton beam, and three quartz windows for the laser beams to allow both traditional collinear single-photon spectroscopy and Doppler-free two-photon spectroscopy. This chamber can be used with the direct 5.3-MeV antiproton beam.

Using the old and new equipment, the following experiments have been made:

High-precision measurements of the wavelengths of transitions between five pairs of metastable and short-lived antiprotonic states in low-density (0.1–5 mbar) ^{4}He and ^{3}He [1]. Using the above-mentioned achromatic spectrometer line to increase the signal-to-noise ratio, the precision of the measured transition wavelengths will likely to increase, which in turn can improve our previously obtained precision of the mass and charge of the antiproton, a test of the *CPT* invariance [2,3].

The above-mentioned measurements at low densities (<1 mbar) revealed that the average lifetime of antiprotons (which can be deduced from the average decay rate of the delayed annihilation time spectra) increases to ~5 microseconds compared to 3.5 microseconds at higher densities (>100 mbar) [4]. This reflects the reduced collisional influence at such low densities.

We also found that at even lower densities (<0.1 mbar), the decay lifetime of the laser-induced annihilation spike becomes significantly longer (~10 ns vs. ~ns) [4]. This indicates that the $\overline{p}-He^{++} \equiv \overline{p}He^{++}$ ion, which is created after the Auger transition from the daughter state of the laser-induced transition, has a longer lifetime due to a reduction of the collisional Stark mixing in such ultra-low density environments.

Discovery of four new laser resonant transitions between antiprotonic states, one in ^{4}He and three in ^{3}He [4]. The wavelengths of these transitions were also measured. A high-resolution scan of one of the transitions revealed a double peak, which is caused by the hyperfine splitting of the parent and daughter states (see Fig. 1).

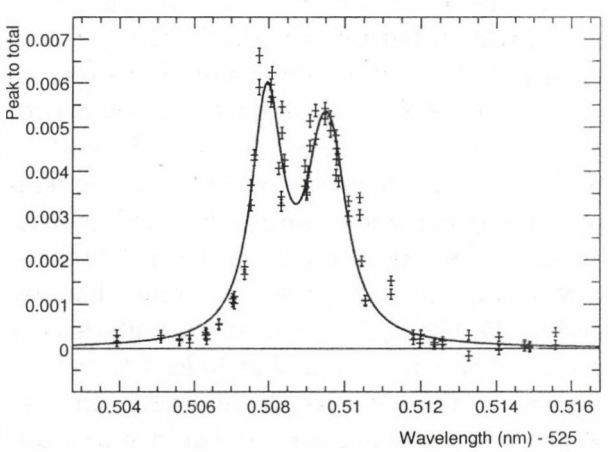

Figure 1. High-resolution scan of a resonance transition with a doublet splitting.

The precision of our previous single-photon measurements was limited by Doppler broad-

ening, which can be eliminated using Doppler-free two-photon laser spectroscopy technique. The feasibility of this method was tested in 2002 using the high-pressure target chamber and two collinear laser beams. The measurements had to made at room temperature, where Doppler broadening is larger than the laser bandwidth so that we can see a narrowing of the resonance line due to Doppler cancelling. The transition was successfully observed, but the measured linewidth was much larger and the signal-to-noise ratio was much smaller than those of the single-photon transitions. The possible reasons for the poor experimental results can be the increased i) collisional broadening, ii) laser bandwidth, iii) laser wavelength and power fluctuations.

Investigation of the temperature dependence of quenching of metastable states in collisions with H_2 and D_2 molecules [5]. According to the theoretical calculations of Sauge and Valiron [6], a state-dependent activation barrier exists for this kind of quenching reaction, which means that the quenching cross section σ_q should increase with increasing temperature following the Arrhenius law:

$$\sigma_q = \sigma_0 \exp(-E_b/kT), \qquad (1)$$

where σ_0 is the cross section at infinitely high temperatures (this we expect to be close to the geometrical cross section), E_b is the height of the activation barrier, k is the Boltzmann constant and T is the temperature. However, all previous measurements of quenching by hydrogen and deuterium molecules were done at 30 K [7]; therefore, in order to test the above temperature dependence, we made measurements at several temperatures: at room temperature using the high-pressure target chamber and at 25–100 K using our usual high-density cryostat, and we found that indeed there is a significant temperature dependence. In case of one antiprotonic state, we could systematically study this dependence by measuring the quenching cross section with deuterium at six temperatures. The collected data, however, favour a different model:

$$\sigma_q = \sigma_0 \exp(-E_b/kT) + \sigma_c, \qquad (2)$$

where σ_c is independent of the temperature. This term is most likely related to the quantum tunnelling of the colliding impurity molecule through the activation barrier. Fig. 2 shows the quenching cross section versus the inverse temperature. A deviation from the Arrhenius law is clearly visible (note the logarithmic scale of the vertical axis). The plotted line is the result of fitting Eq. (2) to the data points.

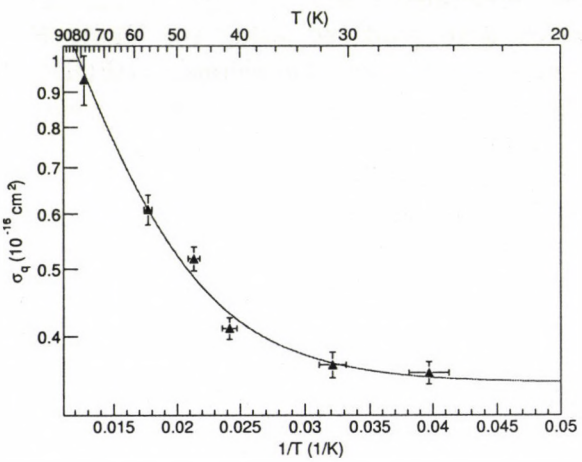

Figure 2. Quenching cross section versus the inverse temperature.

The analysis of the data collected in 2000 and 2001 was partially completed and the results were published [7-10].

Almost all of the support structures of the experimental devices were designed and manufactured in Hungary.

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3.2 An improved description of the multiple ionization $K\beta L^i$ satellite energy spacings

I. Török, T. Papp, S. Raman[a)]

In analytical works, and in basic atomic physics research one needs the data of the satellite lines, therefore we began to make a new compilation of the energy shifts of the $K\alpha L^i M^m N^n$ ..., $K\beta L^i M^m N^n$ ... satellites, and $K^2\alpha L^i M^m N^n$ ..., $K^2\beta L^i M^m N^n$ ... hypersatellites. A byproduct of this compilation is a test of the "classic" description of their energy spacings as a function of Z [1]. The larger database we have now, made it possible, to obtain a better description. For $K\alpha L^i$ satellites see Ref. [2]. The old version gave equidistant spacing also for the $K\beta L^i$ satellites, using an average effective Z seen by the electrons: $\Delta E(K\beta L) = 4.38 Z_L = 4.38(Z - 4.15)$, our version uses an effective Z changing with the number of spectator L vacancies:

$$\Delta E(K\beta L^i) = i \times 3.37[Z + (i-1) \times 0.5 - 5.37]$$
$$i = 1, 2, 3, ..., 7$$

This equation, obtained by fitting a representative portion of our compiled data is in agreement with experimental data, perhaps the $i = 7$ case is a little bit underestimating them, probably because of the significant number of additional M, N vacancies. Full account is given in a paper in preparation.

The work was supported by OTKA No. T016636.

* ORNL is managed by Lockheed Martin Energy Research Corporation under contract No. DE-AC05-96OR22464 with the U.S. Department of Energy.

a) Oak Ridge National Laboratory (ORNL),* Oak Ridge, TN, USA 37831

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3.3 On the measurements of $K^2\beta L^i$ hypersatellites

I. Török

Although we gave a short publication in our institute's Ann. Rep., there was stated in the literarure, that such new formulae for the $K\beta L^i$, and $K^2\beta L^i$ satellites and hypersatellites are not existing. In [1] we gave a semiempirical formula for the $K\alpha L^i$ satellite energies, and in [2] for the $K\beta L^i$ lines, this latter report we republish in this Ann. Rep., with the original title, containing the symbol β (which was lost during the editorial process in the case of first publication), emphasising the new content. Regarding the $K^2\beta L^i$ hypersatellites they were not measured at all by crystal spectrometers.

The $K^2\beta L^i$ hypersatellites are very weak lines. They are regarded, as not available for measurements by crystal spectrometers. Nowadays the situation is changing, the better and better resolution and the use of high efficiency position sensitive detectors makes these hypersatellites to become investigable. In a pair of spectra (Ca and Ti) - I got from the authors (the group of prof. J.-Cl. Dousse) prior to publication [3], - there were a few weak, but definite, although unassigned lines, which comparing to our multiple ionization satellite energy systematics [2], turned to be such hypersatellites, including their $K^2\beta L^i$ satellites. We found also an indication of such hypersatellites for Ti in the literature [4], dated about ten years earlier. The Dousse-group was informed about our observation in their spectra, and as to my knowledge, now a project is running successfully to measure such hypersatellites in the range of elements around Cr.

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3.4 Electron emission from H_2^0 in collisions with He atoms

L. Sarkadi, L. Lugosi, B. Paripás[a] *and B. Palásthy*[a]

The electron emission in energetic ion-atom (atom-atom) collisions has been widely studied in the past decades, and now it is well understood theoretically. At the same time, the information for the electron emission in collisions involving *molecules* is rather scarce.

In the present work we studied the electron ejection from the neutral H_2 molecule in collisions with He atoms at impact energy 150 keV amu^{-1}. The work was motivated by a recent experiment [1] in which evidence was found for the *coherent* electron emission from the two H atoms of the H_2 molecule collided with 60 MeV amu^{-1} Kr^{34+} ions.

Our measurements were performed at the 1.5 MV Van de Graaff accelerator of ATOMKI. We produced neutral H_2 beam by charge exchange of the H_2^+ beam of the accelerator with the residual gas of the beam channel. For normalization we used a H^0 beam of the same velocity. We measured the energy spectra of the ejected electrons at 0°. The electron emission from H_2^0 and H^0 was indentified by detecting the electrons in coincidence with the outgoing H_2^+ and H^+ ions, respectively. The spectra were taken in the cusp region, i.e., we measured the distributions of those electrons which were ejected with small relative kinetic energy with respect to the projectile. The cusp electron production associated with projectile ionization is called *electron loss to the continuum* (ELC). It was an interesting question whether ELC is affected by any interference effect for molecule projectile.

The obtained electron spectra are displayed in Fig. 1. Surprisingly, the width of the ELC peak for the molecular emission is considerably smaller than that for the atomic emission. The ratio of the corresponding cross sections exhibits a pronounced, narrow peak centered at the cusp maximum.

We applied the classical trajectory Monte Carlo (CTMC) method to the description of the ELC process in collisions of H_2^0 and H^0 with He. The coherent electron emission from H_2^0 was treated as it is proposed in Ref. [2]. CTMC predicts a weak dependence of the molecule/atom cross section ratio on the electron energy, in a strong disagreement with the experiment.

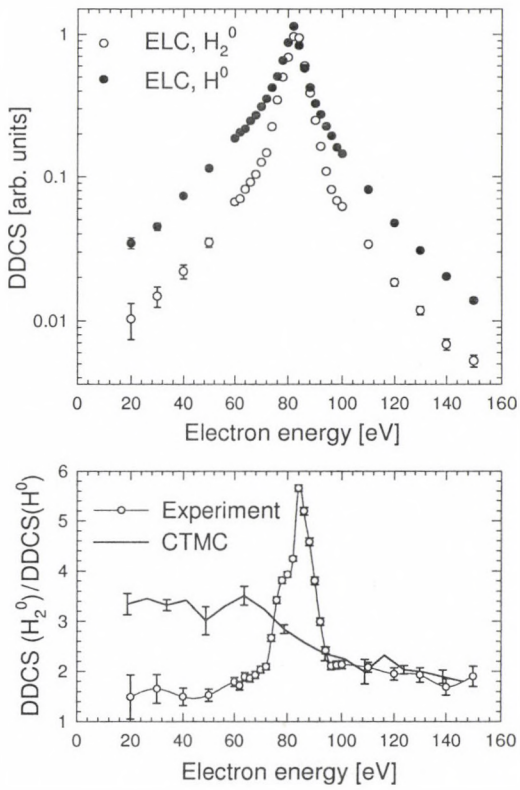

Figure 1. Upper part: Measured relative double differential cross sections (DDCS) for the ELC cusp produced in H_2^0 + He (open circles) and H^0 + He (full circles) collisions. Lower part: Ratio of the measured and calculated DDCS values as a function of the electron energy. The notations: –o–, experiment; —, CTMC theory. The experimental data are normalized to the theorerical curve at 150 eV electron energy.

a) Department of Physics, University of Miskolc, Hungary

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3.5 Strong nondipole effect in $5s$ photoionization of xenon

S. Ricz, R. Sankari[a)], Á. Kövér, M. Jurvansuu[a)], D. Varga, J. Nikkinen[a)], T. Ricsoka, H. Aksela[a)], S. Aksela[a)]

Dipole approximation has often been used successfully to describe the angular distribution of photoelectrons and also to evaluate the experimental angular distribution results. The validity of the dipole approximation comes from the dominance of the dipole interaction at low photon energies ($h\nu \leq 5$ keV). Until recently the contribution of the higher order multipole components were assumed to be negligible.

Intensive theoretical investigations related to nondipole effects at low photon energies began during the last decade. Recent experimental investigations of the photoionization angular distribution [1][2], extending down to 250 eV photon energies, suggested that nondipole effects are of importance at low photon energies.

In present work, the angular distribution of the $5s$ photoelectrons of xenon was measured with linearly polarized light in the 90-225 eV photon energy range in order to determine the dipole (β) and nondipole (δ and γ) parameters. The measurements were carried out at the beam line I411 on the third generation MAX-II storage ring in the Max-Lab, in Lund, Sweden [3][4]. Emitted electrons were detected by 20 channeltrons using ESA-22 electron spectrometer [5], which was installed before the permanent end-station into so called one-meter section. For present measurements the relative energy resolution of the analyzer was set to $\Delta E/E = 2.4 * 10^{-3}$. This resolution and the bandwidth of the photon beam (bandwidth using $120\mu m$ exit slit varied between 0.09 and 0.3 eV depending on incident photon energy) ensured that the Xe $5s$ photoline could be separated from the closest satellite line.

The correct intensity calibration the relative efficiencies of the detectors were determined by using isotropic Ar $L_2 - M_{2,3}M_{2,3}\ ^3P_{0,1,2}$ Auger transitions.

The angular anisotropy parameters were extracted from the experimental, efficiency corrected intensities using equation [6]

$$\frac{d\sigma_{nl}}{d\Omega} = \frac{\sigma_{nl}}{4\pi}\{1 + \beta P_2(\cos\theta) + [\delta + \gamma\cos^2(\theta)]\cos(\phi)\sin(\theta)\} \quad (1)$$

that describes angular distribution of photoelectrons for linearly polarized light. P_2 is the second order Legendre polynomial, σ_{nl} is the photoionization cross section of the nl orbital, β is the anisotropy parameter of the dipole interaction (E1),. δ and γ are the parameters related to the quadrupole interaction (E2), whereas θ and ϕ define the polar and azimuthal angles relative to the polarization vector, respectively.

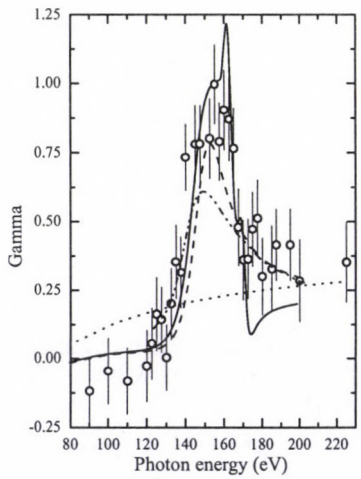

Figure 1. Comparison of the experimental nondipole γ parameters (open circles) with the corresponding theoretical values as a function of the photon energy. Theory: RIPM [8] (dot line), 13-channel RPAE [11] (dash-dot-dot line), 13-channel (dash line) and 20-channel RRPA (solid line) [9]

The dipole and nondipole parameters were obtained by the least squares fitting procedure to Eq. (1). Due to used geometry the δ and γ parameters could be determined separately, however, the δ parameter was found to

be very close to zero as expected theoretically (see e.g.[6] and references therein). The value of the fitted β and γ parameters did not change practically either the δ-parameter was included or not. Figure 1. compares our experimental and theoretical [8][9][12] nondipole γ parameters. The RIPM approximation [8] shows slightly increasing line without any structure, while the γ parameter values calculated with 13 or 20-channel RRPA [9] show an enhancement with maximum around 160 eV. Our experiment shows similar structure than these theoretical predictions. The shape of the experimental cusp is similar to the 20-channel calculation but the maximum of the experimental values is smaller. Comparison between theoretical [8][9][12] and present experimental values shows that the inclusion of the Xe $4s$ and $4p$ channels is important in the description of the energy dependence of the γ parameter in $5s$ ionization. The contribution created by the $4p$ channel is, however, slightly overestimated [9]. This is not surprising as the Xe $4p^{-1}$ is known to correlate with $4d^{-2}nf, \epsilon f$ states and this correlation is not included in the calculations.

Amusia *et al* [12] presented theoretical values for γ parameter in Xe $5s$ photoionization. Their RPA calculations with exchange (RPAE) included coupling between $4d$, $5s$ and $5p$ channels. The values are smaller over the whole energy range of interest than the corresponding values of Johnson and Cheng [9] indicating that relativistic effects are of some importance.

Remaining discrepancies between experiment and theory may be related to the omission of the satellite channels of the type $5p^{-2}nd, \epsilon d$ and $4d^{-1}nf, \epsilon f$ related to the $5s$ and $4p$ ionizations, respectively, in the calculations.

Figure 2. compares the present and the previous [7] experimental β parameters and the corresponding theoretical values [9][10] in the 90-220 eV photon energy range. The results of the relativistic independent particle approximation (RIPA) [8], which omits the coupling between the continuum channels, do not show any sudden changes and β has a constant value of about 2. However, all calculations which take the channel interaction into account predict a broad minimum around 150 eV photon energy. The minimum is deeper in 13-channel than in 20-channel RRPA calculation [9]. The depth further decreases in predictions based on the relativistic time-dependent density functional theory (TDDFT) [10], which include also the correlation related to satellite channels in an average way by a model potential. The present experimentally determined β parameters are between 20-channel RRPA and TDDFT values, slightly closer to the results of the 20-channel RRPA calculations. This indicates that the influence of the $4p$ channel is important in the Xe $5s$ ionization but that the TDDFT fails in accounting the additional correlation correctly. In general, experimental β parameters agree well with theoretical ones [9] except in the 90-130 eV photon energy range where experimental and theoretical values deviate significantly (~10%).

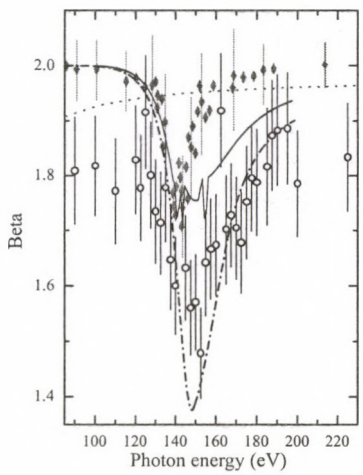

Figure 2. Comparison of the present experimental angular distribution β parameters (open circles) with the earlier experimental results of Hemmers *et al* [7] (diamonds) and with the theoretical values: RIPM[8] (dot line), 20-channel RRPA [9] (dash-dot line), TDDFT [10] (solid line).

Recently Hemmers *et al* [7] published experimental β parameters in this energy region. The agreement with our experimental results is good at the low-energy side of the dip (see Fig. 2), but not on the high-energy side. Their

beta values show narrower and shallower dip than ours or the calculated ones [9]. Furthermore the position of the minimum is shifted to lower photon energies. The difference between the two experimental results requires further investigations.

The effects of the nondipole interaction are remarkable over a wide photon energy range. Especially, at 155 eV photon energy, where the γ parameter reaches its maximum, the nondipole contribution to total angular distribution is as high as 20%. It is clearly enough to question the validity of the dipole approximation in photoionization of the Xe $5s$ subshell relative far from the ionization threshold.

Acknowledgements

The staff of MAX-laboratory is acknowledged for assistance during the measurements. This work has supported by the Research Council for Natural Sciences and Technology of the Academy of Finland. The work was also supported by the Hungarian Scientific Research Foundation (OTKA Grant No: T025325) and by the European Community's ARI-Program.

a) Department of Physical Sciences, P.O. Box 3000, 90014 University of Oulu, Finland

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3.6 X-ray imaging of ECRIS plasmas

E. Takács [a,b], S. Biri, A. Valek, J. Pálinkás [a], Cs. Szabó [b], L.T. Hudson [b], B. Juhász, T. Suta, J. Imrek [a] and B. Radics [a]

Introduction

Highly charged ion plasmas generated in the ATOMKI ECR ion source had been imaged using an X-ray CCD device of the National Institute of Standards and Technology (NIST). The motivations for the experiments came from possible future high-resolution X-ray spectroscopic measurements using X-ray microcalorimeters and crystal spectrometers. In the present set of experiments, the general distribution of the emitting highly charged ion cloud and its systematic dependence on various operating parameters were the focus of our interest. Understanding the details of the ion production and confinement provides insight into the operation of the ECR ion source and gives important information for our future spectroscopic plans. In addition to its source diagnostic value, the X-ray imaging and spectroscopy of highly charged ion plasmas can also be utilized for the laboratory investigation of plasmas of astrophysical and other interests.

X-ray imaging

The NIST CCD camera used in these experiments has 1152x1242 pixels in a rectangular arrangement. The imaging was achieved using an appropriately positioned 70 micrometer diameter X-ray pinhole. The CCD chip was thermoelectrically cooled to about $-45°C$ to reduce thermal noise. Each pixel can be used in single photon detection mode with an energy resolution of about 180 eV. This feature allows the post detection filtering of the obtained images according to the wavelength of the detected X-ray photons. This can be used to discriminate certain characteristic line emission features in the spectra to determine their distribution in the plasma [1]. The data acquisition and analysis system was partly developed by us using the ROOT data analysis library.

ECR plasmas

For our imaging studies, we have operated the ECR under different running conditions in order to better understand the dynamics of the ion generation. We used working gases of Ar, Xe, O_2, and solid ferrocene (an organic compound containing Fe). In order to have a clear view of the source the injection side end cap of the plasma chamber has been modified. The pinhole was mounted 91 cm from the center of the plasma and the pinhole – CCD distance was 25 cm forming an X-ray camera with demagnification of 3.6. This permitted more than half of the plasma volume to be imaged through a course mesh; considered to be sufficient because of the 120 degree symmetry of the ECRIS.

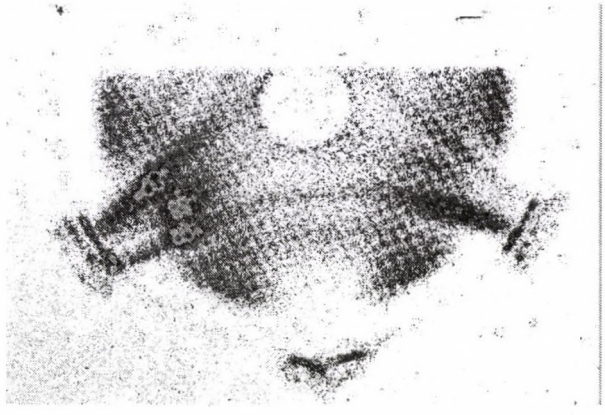

Figure 1. Image generated by an Ar plasma in the ATOMKI ECRIS.

Systematic studies

In these first sets of imaging measurements, the basic features of the ECR plasma X-ray emission were studied under different running conditions. An image generated by an Ar plasma is shown in Figure 1. The upper part of the source is vignetted by a horizontal cut due to the design of the injection side end cap. The two arms showing strong emission

are mainly due to bremsstrahlung and characteristic X-rays generated by high-energy electrons impinging onto the opposite side end cap. The circular aperture of the extraction hole is clearly visible in the center. In a completely different process the more or less circular plasma cloud emits characteristic radiation of the Ar working gas caused by core vacancy creation due to electron impact. An interesting feature is the upside down triangle showing reduced intensity emission, which we tentatively attribute to X-ray absorption within

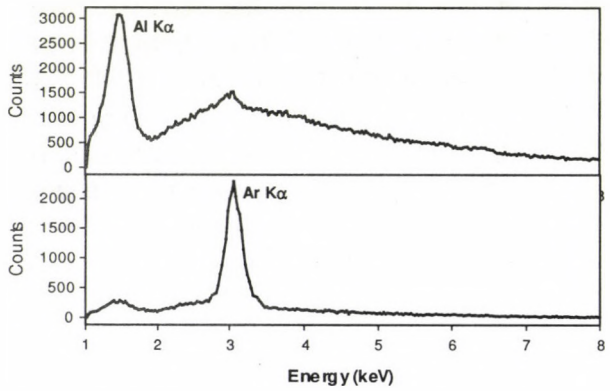

Figure 2. X-ray spectra from different parts of Figure 1.

Several sets of images similar to Figure 1 have been taken under different running conditions in order to study the origin of the different features in the pictures. These include running the ECRIS in low and high power modes, at different magnetic field settings, and turning the ion extraction on and off etc. We took pictures of mixed plasmas (Ar + Xe, Ar + O_2) as well. In addition to the images that have several X-ray photons hitting a single pixel during the exposure, we have also taken low light level images. In these cases, the collected charge in a single CCD pixel is proportional to the energy of the detected X-ray photon, therefore, under these conditions spectral analysis of the X-rays is also possible. As an example Figure 2 shows two of such spectra obtained under the same running conditions as Figure 1. The spectra are from two different regions of the image, the upper corresponding to one of the bright arms and the lower to a region of the Ar plasma cloud. The difference in the strength of the different characteristic emission lines is clearly visible indicating the size and distribution of the plasma (Ar emission) as contrasted with the Al emission from electrons striking the end walls of the plasma chamber. The analysis of the large amounts of data and model calculations are under way.

Conclusions

X-ray images taken under different ECRIS running conditions reveal the hottest, most energetic regions of the plasma. Spectral filtering allows us to study the origin of certain spectral features (e.g. characteristic lines, bremsstrahlung continuum) in the plasma, which can help to improve modeling of the source and other magnetically confined plasmas.

a) Department of Experimental Physics, University of Debrecen, Hungary

b) National Institute of Standards and Technology, Gaithersburg, MD, USA

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3.7 Cascade transition x-rays from electron capture into highly charged ions in collisions with neutral gas targets

H. Tawara [a], E. Takács [a,b], L.P. Ratliff [a], J.D. Gillaspy [a] and K. Tőkési

In collisions of low energy (few keV/u), highly charged ions (HCIs) with neutral atoms, the electron capture process is far dominant over other processes such as excitation or ionization. It is well established that an electron from a target atom is usually captured into high a Rydberg state of the projectile ion [1]. Even in multi-electron target atoms, single electron capture is generally dominant, though the contribution of double and triple electron capture becomes significant for higher ion charge states. In the case of multiple electron capture, Auger electron emission becomes an important first step of the relaxation process [2]. In essentially all cases (single or multiple capture), however, the stabilization ends in a cascade of photon emitting transitions. When the projectiles are highly charged, the photons emitted in these final steps are x-rays. The observation of these x-rays can provide information on both the electron capture and the following cascade. Recently, the unexpected observation of x-rays from comets and other objects of the solar system [3] brought the collisions of highly ionized projectiles with neutral gases into the forefront of research.

Using the electron beam ion trap (EBIT) [4] and extraction facility [5] at the National Institute of Standards and Technology (NIST), we have performed a series of systematic collision studies with different projectile and target combinations. X-rays originating from a series of the cascades after electron capture into highly excited Rydberg states have been observed from low energy, highly charged Kr^{q+} ions (q=27-36) colliding with neutral Ar atoms. We found that the intensity ratio between L (n=32) x-rays and the sum of M x-rays (n=43, n=53, n=63 etc.) is drastically changed from Kr^{27+} to Kr^{28+} and constant for higher ion charge states (q=29-36). This feature can be understood to be due to the metastable states formed during cascades after electron capture into Kr^{27+} ions. This is also supported by time-dependent population calculations.

a) NIST, Gaithersburg, MD 20899-8421, USA

b) Debrecen University, Debrecen, Bem t 18/a H-4026

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3.8 Double 1s ionization of Mg and Si induced in collisions with fast heavy ions

M. Kobal[a)], M. Kavčič[a)], M. Budnar[a)], J.-CI. Dousse[b)] and K. Tőkési

The Kα x-ray emission spectra of Mg and Si excited with 34 MeV C ions and 50 MeV Ne ions have been measured with a von Hamos crystal spectrometer [1]. The energy resolution of approximately 0.5 eV was achieved enabling us to distinguish contributions originating from states with different number of holes in K and L shells. In order to determine the intensity of the hypersatellite and satellite lines the model spectra based on the MCDF calculations was constructed and fitted to the measured spectra. The intensities of the measured hypersatellite and satellite lines were used to determine the yield of the K^XL^N vacancy states produced in the collision, taking into account whole decay scheme of the particular initial K^XL^N ionized state. The decay scheme has been calculated using the initial rates of the radiative and nonradiative transitions from [2, 3] which were then corrected for additional vacancies in the inner shell according to statistical approach, first proposed by Larkins[4].

From the yield of the doubly 1s ionized states (K^2XL^N) produced in the collisions relative to the singly 1s ionized states (K^1L^N) the ratio of double to single 1s ionization cross section has been obtained. The double to single 1s ionization cross section has been also calculated in the independent electron model using the one electron ionization probabilities calculated within the three body classical trajectory Monte-Carlo simulation (CTMC). The calculated values are presented in Table 1. In such nearly symmetric collisions electron capture by the projectile is actually the dominant ionization mechanism. Since the capture in the 1s shell of the projectile is by far the strongest the ionization cross section depend significantly on the charge of the projectile. In Table 1 we can find the calculated values for the projectile with 0, 1, 2 electrons in its K shell and for the projectile with the average equilibrium charge in the solid target used in our experiment.

Table 1. Double to single 1s ionization cross section, σ_d/σ_s, (in %) calculated with the CTMC model for the measured collisions. Tabulated are the calculated values for the projectile with **0,1,2** K shell electrons and for the projectile with the average equilibrium charge in the solid target used in the experiment. a: 34 MeV $C^{6+} \rightarrow$ Mg, b: 50 MeV $Ne^{10+} \rightarrow$ Mg, c: 34 MeV $C^{6+} \rightarrow$ Si, d: 50 MeV $Ne^{10+} \rightarrow$ Si.

	(0)	**(1)**	**(2)**	**(av.)**
a	16.6	12.3	10.2	15.8
b	24.1	12.5	11.7	15.3
c	12.2	8.4	7.6	11.6
d	12.2	7.5	8.2	9.0

We found, except for the case of 34 MeV $C^{6+} \rightarrow$ Mg collision, a relatively good agreement between the experimental and calculated data.

a) Jožef Stefan Institute, Ljubljana

b) Physics Department, University of Fribourg

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3.9 Fermi-shuttle acceleration in low and intermediate velocity ion-atom collisions

B. Sulik[a], *R. Hellhammer*[b], *Z.D. Pešić*[b] *and N. Stolterfoht*[b]

We have been performing a systematic search for accelerating multiple scattering sequences of electrons emitted in ion-atom collisions (or Fermi-shuttle type ionization [1]). In this process, the liberated electron is repeatedly backscattered by the projectile and the target center (denoted by P and T respectively). With the impact velocity of the projectile V, scattering sequences starting with target ionization produce electrons emitted with the mean velocity 2nV in both forward and backward directions, where n is the number of encounters with the projectile. Starting with projectile ionization, the corresponding mean velocity is (2n+1)V.

In a recent work [2], experimental evidence has been found for consecutive P-T-P (projectile-target-projectile) and P-T-P-T ping-pong-like scattering of ionized target electrons in single C^+ + Xe collisions at 150 and 233 keV/u impact energies. Distinct signatures for triple and quadruple electron scattering have been separated. Typical signature was the excess electron intensity emitted forward and backward in the expected velocity regions.

In the present work, we search for longer sequences in a significantly lower impact velocity range. In an earlier experimental study [3], distinct structures of excess electron yields at forward and backward directions have been observed in collisions of 50-400 keV O^+ ions with Ar target. These structures appeared to be shifted with the projectile velocity [3]. In our present experiments, performed at the beamline of the ECR ion source of the Ionen-Strahl Labor (ISL) in Hahn-Meitner Institute Berlin, we studied the spectra of electrons emitted in collisions of 15 keV N^+ ions with Ar atoms under single collision condition. At this low velocity, we enter the impact energy range, where the accelerating electron "orbits" may be considered as specific molecular orbitals, and the Fermi-shuttle process might be treated as a promotion mechanism [4]. Our preliminary results show a a significant forward-backward enhancement in the yield of continuous electrons in the 20-100 eV energy range, indicating the presence of 6-12-fold accelerating multiple scattering in the collisions (Fig. 1). Further experimental and theoretical work is needed to confirm these findings.

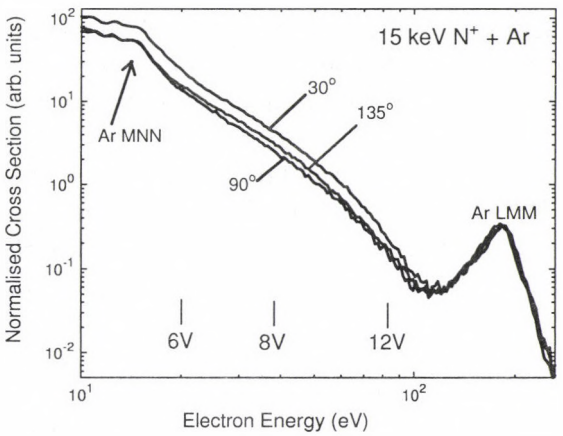

Figure 1. Double differential cross sections for electron emission in 15 keV N+ + Ar collisions, normalized to the Ar LMM Auger group. Multiples of the projectile velocity are indicated.

Acknowledgements

We acknowledge support from the OTKA Grant No. T032942, and the Hungarian-German Intergovernmental S&T Collaboration No. D17/99.

a) A significant part of the work was performed during a guest-scientist period in Hahn-Meitner Institute, Berlin.

b) Hahn-Meitner Institute, Glienickerstr. 100, D-14109 Berlin, Germany

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3.10 Electron emission from collisions of H_2^+ molecule ions with inert gas targets: Search for interference patterns

B. Sulik, T. Ricsóka, O. Turák and N. Stolterfoht[a)]

In recent years, particular attention has been devoted to charged particle induced ionization of the H_2 molecule. Since the two atomic centers in this simple molecule can not be distinguished, their electron emission contributions add coherently. First experimental evidence for such interference effects has been found in the electron emission spectra in collisions of very fast and highly charged (60 MeV/u $Kr34^+$) projectiles with H_2 molecules [1]. In subsequent theoretical studies [2,3], the basic features have been analyzed. In a recent experimental study, some of their prediction has been verified [4].

The simplest molecular system, however, is not H_2 with two electrons, but the H_2^+ molecular ion. At first sight, the symmetries of the H_2 molecule are also present in this one-electron system, but electron-electron interactions do not alter the picture.

In the present work, we studied electron emission from H_2^+ molecule ions colliding with He and Ar targets (the inverse collision system). A beam of 1.5 MeV/u H_2^+ ions was directed to gas jet targets, and electron spectra were collected in the entire 0-180^o angular range. The experiments have been performed at the beamline of a 5 MV Van de Graaff accelerator in ATOMKI, Debrecen. For reference purposes, we also collected spectra in collisions of 1.5 MeV H^0 atoms with the same targets.

In Ref. [2], interference was treated within a two-effective center approximation, which partially accounts the correlation between the emitted and bound electrons. It is not clear, whether interference is only due to symmetry properties, or electron correlation in H_2 also plays a significant role.

Our present experiments are expected to answer this question too. We have found clear differences between atomic (H^0) and molecular (H_2^+) bombardment with the same impact velocity. Preliminary results are shown in Figure 1, comparing the cross sections for H^0 and H_2^+ impact at 165^o. Beyond the shape-difference, a crossing point exhibits at 1140 eV, indicating the presence of interference effects. The oscillation frequency seems to be doubled compared to first order expectations [1,2]. This is in agreement with the picture that electron loss at backward angles is due to hard collisions. Our data also resemble a recent observation of double frequency components for H_2 [5]. Further analysis is in progress.

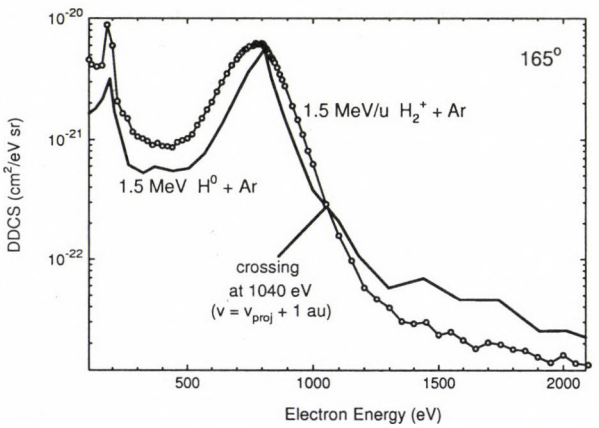

Figure 1. Double differential electron emission cross sections at 165^o observation angle in collisions of H atoms and H_2^+ molecules with Ar. .

Acknowledgements
We acknowledge support from the Hungarian OTKA Grant No. T032942, and the Hungarian-German Intergovernmental S&T Collaboration No. D17/99.

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3.11 Cascade feeding of the $1s2s2p\,^4P$ state in collisions of Li-like O^{5+} ions with H_2 and He targets

B. Sulik, A. Orbán, L. Gulyás and T.J.M. Zouros[a)]

In the collisional formation of the $1s2s2p\,^4P$ state of Li-like ions, one of the possible mechanisms is the so-called transfer-loss (TL) process, in which the loss (ionisation) of a projectile $1s$ electron occurs simultaneously with the transfer of a target $1s$ electron to the projectile $2p$ subshell. This process was studied experimentally in 0.2-2 MeV/u collisions of O^{5+} ions with H_2 and He targets [1]:

$$O^{5+}(1s^22s)+He \rightarrow O^{5+}(1s2s2p^4P)+He^+ + e^-.$$

In our earlier analysis [2] we have shown that the TL process could be described qualitatively, within the framework of the independent particle model (IPM). In the present work, we show that inclusion of capture to higher n shells of the projectile provides significantly improved agreement with experiment. The basic idea is that practically all capture into higher-lying ($n > 2$) quartet states decay radiatively very quickly to the $1s2s2p\,^4P$ state. These photon cascades become increasingly more likely than autoionization with increasing n. Due to the strongly different decay rates, the metastable $1s2s2p\,^4P$ state behaves like a quasi-ground state, collecting all quartet capture events before decaying itself.

Compared to our earlier study [2], only the transfer probability was calculated differently:

$$P_T^{2pm} = P_{He(1s)\rightarrow O(2p)} + P_{He(1s)\rightarrow O(n>2)}$$

where the first term is the probability of the capture of a He $1s$ electron to the O^5+ $2p$ state by a He or H_2 $1s$ electron (original term from our earlier work [2]), and the second term represents capture to all O^5+ $n > 2$ shells.

Similarly to our previous work [2], calculations of projectile excitation and ionization probabilities were performed by an SCA code [3], while electron transfer probabilities were calculated in the CDW approximation [4].

In Fig. 1, experimental data for the $O^5+ + H_2$ collission system [1] are compared with our present (denoted by "cascade TL + T^2L") and earlier calculations (TL + T^2L). It is clearly seen, that the inclusion of the cascade feeding into the calculations significantly improved the agreement with experiment.

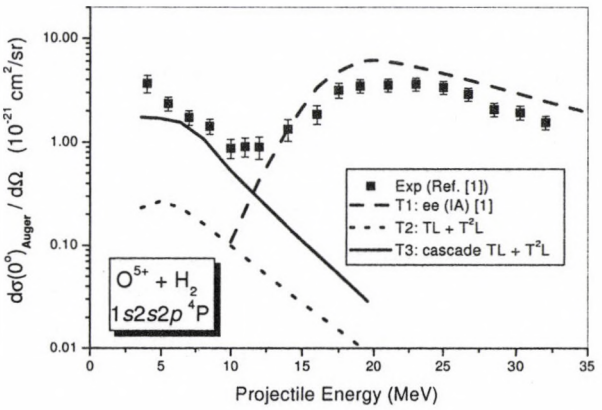

Figure 1. Single differential cross sections for zero-degree Auger electron emission from the $1s2s2p\,^4P$ state as a function of projectile energy for collisions with H2. The symbols are for experimental data [1]. The dotted line represents the earlier TL calculations without cascade feeding, while the solid line is the present full TL calculation. The dashed line is a calculation for the dielectronic excitation (eeE) within the electron scattering model [1].

Acknowledgements

We acknowledge support from the Hungarian OTKA Grant No. T032942, and the Hungarian-Greek Intergovernmental S&T Collaboration No. GR-08/99.

a) Department of Physics, University of Crete & I.E.S.L.-F.O.R.T.H., Heraklion, Crete, Greece

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3.12 Guided transmission of 3 keV Ne^{7+} ions through nanocapillaries in PET polymers: dependence on the capillary diameter

N. Stolterfoht[a)], R. Hellhammer[a)], Z.D. Pešić[a)], V. Hoffmann[a)], S. Petrov[a)], D. Fink[a)], B. Sulik[b)]

The outstanding progress in nanotechnology is accompanied by a continuous miniaturization of interfaces used in microelectronics and related fields. Particular attention has been paid to linear structures of mesoscopic dimensions, such as pores or capillaries. Recently, we started experiments in which PET (Mylar) polymer foils of 10 ĺm thickness were irradiated by 400 MeV xenon. Capillaries with a diameter of a few hundreds nm in foil were obtained etching ion tracks using NaOH [1].

To study the capillary interior, we measured the transmission of 3 keV $Ne^{7}+$ ions through capillaries. Foils with different capillary diameters (100 nm [1], and 200 nm) were tilted with respect to the incident beam direction. Angular distributions of the transmitted Ne^{7+} ions obtained with PET material were found to be essentially different from the results with capillaries covered by a thin Ag metal film. For the latter case, the Ne^{7+} angular distribution is rather narrow (FWHM of 1^0) and ion transmission vanishes when the foil is tilted (Fig. 1). On the contrary, for the 5^0 tilted isolating PET foil only about 20the angular distribution of the Ne^{7+} ions is relatively broad (FWHM of 4^0-6^0). Similar effects were found for tilt angles as large as 25^0 .

The latter observation suggests a "guidance" of the Ne^{7+} ion within the capillary [1], providing evidence that the capillary walls become charged and close collisions with the surface are suppressed. The charge deposition occurs by means of a self-organizing process [1]

From Fig. 1 it is seen that the transmissions of the ions depend both on the tilt angle and the capillary diameter. Specifically, for 0^0 tilt angle the transmissions are about equal for the two capillary diameters, whereas for 15^0 tilt angle the transmission through 100 nm capillaries is about an order of magnitude larger than that for 200 nm. This finding strongly supports the picture of ion guiding in the capillary. The higher the aspect ratio of the capillary the higher the capability to bend the ions along the axis of the capillary and transport them to its exit.

Experimental studies of the time evolution [1,2] of the transmission also support the picture of ion guiding, and provide possibility to verify and refine the developed linear [1] and nonlinear [2] self organizing charge deposition models.

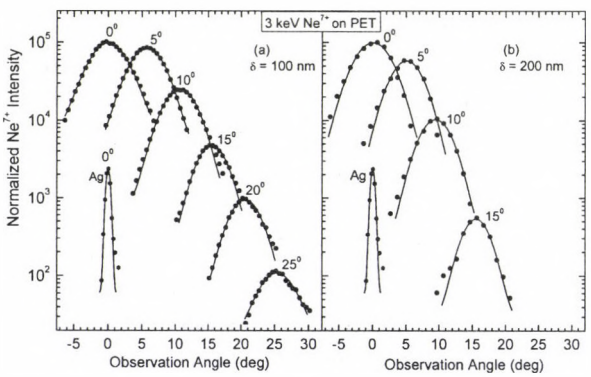

Figure 1. Angular distributions of Ne^{7+} ions transmitted through capillaries in PET. The tilt angle is indicated. Also plotted are data for capillaries in Ag. In (a) and (b) results for capillary diameters of 100 and 200 nm are compared.

Acknowledgements

a) Hahn-Meitner Institute Berlin, Glienickerstr. 100, D-14109 Berlin, Germany

b) A significant part of the work was performed during a guest-scientist period in Hahn-Meitner Institute, Berlin.

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3.13 Theoretical study of transfer ionization in O^{8+} + Ar collisions

L. Sarkadi

We continued the theoretical study of the transfer ionization (TI) process in energetic O^{8+} + Ar collisions. TI is a two-electron process in which the ejection of an electron into the continuum is associated with capture of another electron into one of the bound states of the projectile. Particularly we are interested in a special kind of TI when the electron is ejected in forward direction with the velocity of the bombarding particle. For such an electron emission the long interaction time with the projectile results in a singularity in the energy spectrum of the electrons, known as 'electron cusp'. The formation of cusp associated with target ionization is called *electron capture to the continuum* (ECC). TI proceeding with cusp formation is a special kind of double electron capture: one electron is captured to a bound state, the other electron is captured to a continuum state of the projectile.

TI has been subject of numerous experimental and theoretical investigations, mainly because as a two-electron process it may provide information about the role of electron-electron interaction (correlation) in atomic collisions. The present theoretical work is connected to our previous systematic experimental investigations dealing with cusp-electron emission via TI (for a review see [1]). These studies were carried out with H^+, He^+, He^{2+}, O^{7+} and O^{8+} projectile ions in a broad range of the collision velocity (from 4.4 keV amu^{-1} to 1.5 MeV amu^{-1}).

We applied the classical trajectory Monte Carlo (CTMC) method to calculate the electron spectra of the cusp peak and the TI/ECC cusp-intensity ratios for 0.3 – 2 MeV amu^{-1} O^{8+} + Ar collisions. (We mean ECC 'pure' cusp-electron production, i.e., electron emission without bound-state capture.) We carried out the calculations in the independent particle model (IPM) by considering a reduced collision system consisting of the projectile, an active electron and the target ion core. The role of the passive electrons of the target core was taken into account by an effective potential.

Including the contributions of the L and M shell of the Ar target in the calculations, we showed that the maximum observed experimentally [2] in the impact-energy dependence of TI/ECC cusp-intensity ratios is due to the increasing role of the L shell with increasing energy. The obtained results are shown in Fig. 1. In the figure experimental and theoretical data for He^{2+} ion projectiles are also plotted. CTMC succeeded in the description of the 2TI/ECC ratio, too (2TI: electron emission accompanied by bound-state capture of two electrons).

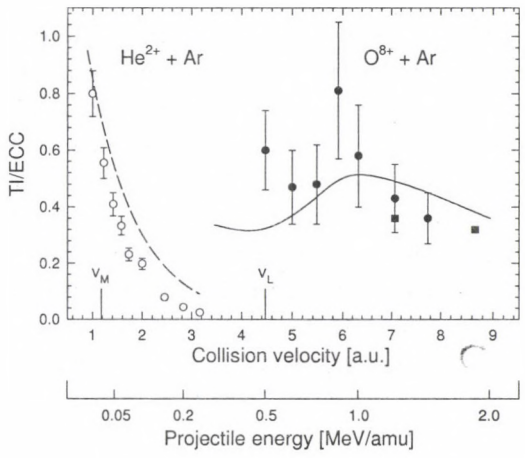

Figure 1. Cusp-electron production by TI relative to ECC. Experimental data for O^{8+} on Ar: full circles, Závodszky et al. [2]; full squares, Breinig et al. [3]. Experimental data for He^{2+} on Ar: open circles, Víkor et al. [4]. CTMC calculations: solid line, O^{8+} on Ar (L and M shell, present work); dashed line, He^{2+} on Ar [1] (M shell only). The v_M and v_L Bohr velocities of the M- and L-shell electrons are indicated by vertical lines.

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3.14 Interference effects in electron emission from 68 MeV amu^{-1} Kr^{33+} + H_2 collisions

L. Sarkadi

We suggest a simple method for the description of the coherent electron emission from the two H atoms of the H_2 molecule induced by particle impact. The existence of the interference effect – an analogy of the Young's two-slit experiment in optics – was demonstrated experimentally by Stolterfoht et al. [1]. Our method is based on a formalism that separates the cross section for the electron emission into an atomic part describing the independent emission from the two H atoms, and a factor giving account of the interference caused by the coherent emission from the two centers:

$$\frac{\mathrm{d}^3\sigma_{H_2}}{\mathrm{d}\mathbf{q}\,\mathrm{d}\Omega\,\mathrm{d}\epsilon} = \frac{\mathrm{d}^3\sigma_{2H}}{\mathrm{d}\mathbf{q}\,\mathrm{d}\Omega\,\mathrm{d}\epsilon}\left[1 + \frac{\sin(pd)}{pd}\right]. \qquad (1)$$

Here $\mathrm{d}^3\sigma_{H_2}/\mathrm{d}\mathbf{q}\,\mathrm{d}\Omega\,\mathrm{d}\epsilon$ is the triply differential cross section for the electron emission from the H_2 target molecule, and $\mathrm{d}^3\sigma_{2H}/\mathrm{d}\mathbf{q}\,\mathrm{d}\Omega\,\mathrm{d}\epsilon$ is the corresponding cross section for the electron emission from the two H atoms acting as independent particles (denoted by the label 2H). $\mathbf{q}$ is the momentum transfer vector defined as the difference between the initial and final momentum of the projectile. The solid angle $\mathrm{d}\Omega$ and the energy $\mathrm{d}\epsilon$ refer to the ejected electron. The factor in the parentheses describes the interference caused by the coherent emission of the electron from the two H centers. In the interference factor p is the modulus of the vector $\mathbf{p} = \mathbf{k} - \mathbf{q}$, where $\mathbf{k}$ is the momentum of the electron. d is the internuclear distance in the H_2 molecule. Since in the experiment the vector $\mathbf{q}$ was not measured, Eq. (1) has to be integrated over $\mathbf{q}$.

The above separability allows the use of a classical ionization theory to determine the atomic part of the cross section. To this we applied the classical trajectory Monte Carlo (CTMC) method. We showed that within CTMC the doubly differential cross section (DDCS) for the molecular electron emission can be evaluated in a very simple way.

Calculations have been carried out for 68 MeV amu^{-1} Kr^{33+} on H_2 collisions. A reasonable agreement has been found between the CTMC results and the recent experimental data obtained by Stolterfoht et al. [2], as well as the predictions of the first Born approximation (see Fig. 1).

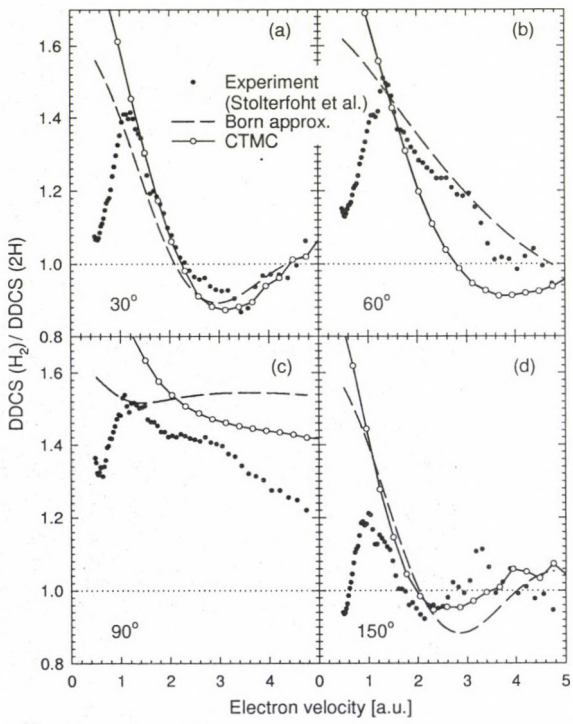

Figure 1. Comparison of experimental and theoretical DDCS(H_2)/DDCS(2H) ratios as a function of the electron velocity for (a) 30°, (b) 60°, (c) 90° and (d) 150° electron emission angles. The notations: •, experimental data [2] normalized to CDW-EIS [3] atomic cross sections; - - -, Born approximation [2]; –o–, CTMC (present work).

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3.15 Classical description of the fragmentation of positronium in collision with He atoms

L. Sarkadi

Recently Armitage et al. [1] reported on first measurement of absolute break-up cross section for the fragmentation of positronium (Ps) in collision with He atoms in the energy range between 13 and 33 eV. In addition to the measurement of total cross sections, they determined also the longitudinal energy distributions of the emitted positrons. A remarkable feature of the obtained positron spectra is a peak appearing just below 50% of the residual Ps energy ($E_{\rm res} = E_{\rm Ps} - 6.8$ eV). The peak was interpreted as an analogy of the *electron loss to the continuum* (ELC) peak appearing in the energy spectrum of the electrons ejected in the forward direction in ion-atom (atom-atom) collisions. In a previous experiment the related process, *electron capture to the continuum* (ECC) has been observed by Kövér et al. [2] for positron projectiles.

We applied the classical trajectory Monte Carlo (CTMC) method to the description of the collisional fragmentation of PS. The collision system was simplified to a three-body system consisting of the electron and the positron of Ps, as well as the He atom that was considered as a structureless particle. The interaction of e^- and e^+ with He was approximated by a static, fully screened Coulomb potential. The calculations were carried out for collision energies 13, 18, 25, and 33 eV. Our theory overestimates the measured total break-up cross sections by a factor of 1.6 – 2.5. At the same time, it correctly reproduces the peak observed in the longitudinal positron spectra (see Fig. 1), supporting a peak formation mechanism similar to the ELC process in atomic collisions.

The dependence of the e^- and e^+ ejection on the emission energy and angle was also investigated by the CTMC model. A strong e^- – e^+ asymmetry was found for the doubly differential cross sections at low impact energy. This behaviour was explained by the polarization of the Ps atom in the incoming phase of the collision. The asymmetry is expected to diminish at high impact energies.

According to the calculations, a significant e^- – e^+ difference is expected to occur also in the longitudinal energy distributions of the ejected particles. CTMC predicts a peak also in the electron spectrum, but it is less pronounced and shows a larger shift from the expected peak position $E_{\rm res}/2$ than the corresponding peak in the positron spectrum. An experiment is suggested in which the longitudinal energy distribution of the electrons emitted in the fragmentation of Ps would be measured.

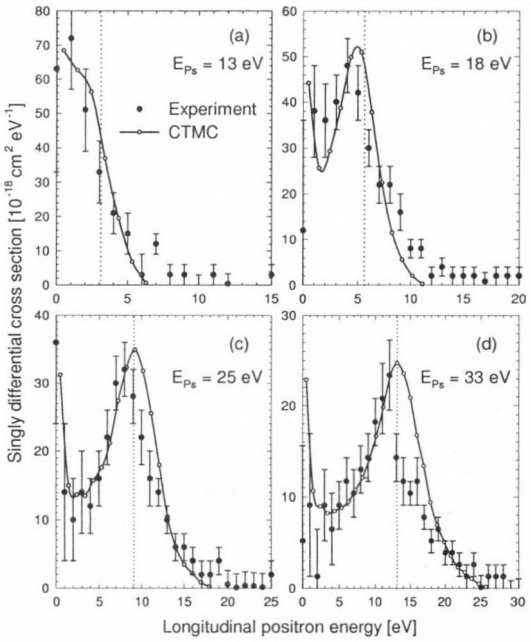

Figure 1. Longitudinal energy distributions of the positrons emitted in Ps + He collisions for $E_{\rm Ps}$ =13, 18, 25, and 33 eV. The experimental data (full circles, Armitage et al. [1]) are normalized to the maxima of the theoretical curves calculated by the present CTMC model. The vertical dotted line shows the expected peak position, $E_{\rm res}/2$.

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3.16 Transition matrix elements for atomic excitations induced by screened Coulomb potentials

A. Orbán and B. Sulik

In ion-atom collisions the electrons carried by the projectile may influence the target electronic transitions. The electric field created by these electrons screens the Coulomb field of the projectile nucleus. The transition matrix elements, which take into account the screening effect of the projectile are important quantities in the description of such collisions. In the literature, there exist codes, which were built up for calculating matrix elements for the pure Coulomb potential in bound-bound and bound-continuum transitions using hydrogenic wave functions for the atomic states description [1], [2]. Recently, we have published a FORTRAN code [3] which calculates transition matrix elements between atomic bound states with high accuracy as a function of the internuclear distance. Compared with the former codes mentioned above, the present program takes into account the screening effect of the projectile electrons. Moreover arbitrary wave functions, given by the user, can be used for the target atomic states description. We applied the screening model already published in Ref. [4]. For an accurate numerical evaluation of the radial integrals, two main problems appeared. One of them is connected to the fact that in the expression of the screening matrix elements the derivatives of different orders of the modified Bessel functions $I_{n+1/2}(x)$ and $K_{n+1/2}(x)$ appear. We developed a relative simple procedure for the calculation of these derivatives, by expressing them with the help of lower order Bessel functions. Consequently, the accuracy of the screening matrix elements depends on the accurate calculation of the modified Bessel functions. We have built up two subroutines for the calculation of these Bessel functions with a relative accuracy better than 10^{-10} in a wide range of order and argument. The other problem is that the target wave functions are given by the user on arbitrary grid leading to numerical inaccuracies. The radial integral is evaluated in three phases. The integral between 0 and the first non-zero coordinate where the wave function is given by the user is approximated analytically. The remaining two parts of the integral is evaluated numerically, using the equidistant method of Simpson from the first non-zero coordinate to the internuclear distance, and from the internuclear distance to infinity. Detailed tests have been performed at different levels, for different collision systems using hydrogenic wave functions (in tabulated form). For reference, the same calculations have been done by Mathematica [5] using the same wave functions in analytical form. For illustrating the accuracy of the code, we present the results for the dipol transitions $1s \rightarrow 2p$ of F^{8+} ion in collision with He atom in Table 1. The table contains the G function (the radial part of the integral) for a few internuclear distances, R. The first, second and third rows of the table contain the $G(R)$ function in the different integration regions while the forth row is the full $G(R)$ function. In the last coloumn 'valuable digits' indicates the accuarcy of the present calculation with respect to Mathematica.

We have also applied the code for the investigation of single excited states of the lithium like oxygen ion [6].

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Table 1. The $G(R)$ function for the $1s \rightarrow 2p$ transition of the F^{8+} ion induced by He projectile.

R	$G_{SCRMTRX}(R)$	$G_{Mathematica}(R)$	*valuable digits*
0.0023	-0.107049057799E-04	-0.107049010129E-04	7
	-0.199805146162E-05	-0.199804344447E-05	5
	-0.657339136625E-01	-0.657339136624E-01	11
	-0.657466166197E-01	-0.657466166068E-01	(10)
0.005	-0.226515644747E-05	-0.226515543329E-05	6
	-0.124340968808E-03	-0.124340967886E-03	8
	-0.142649340630E+00	-0.142649340630E+00	12
	-0.142775946755E+00	-0.142775946753E+00	(10)
0.05	-0.226355769419E-07	-0.226355661376E-07	6
	-0.766151624559E-01	-0.766151624560E-01	10
	-0.121377765792E+01	-0.121377765791E+01	11
	-0.129039284290E+01	-0.129039284300E+01	(9)
0.2	-0.137156290499E-08	-0.137156185166E-08	6
	-0.955011528055E+00	-0.955011528055E+00	12
	-0.134730816477E+01	-0.134730816477E+01	12
	-0.230231969420E+01	-0.230231969419E+01	(12)
0.5	-0.172240208223E-09	-0.172239971614E-09	4
	-0.727617188910E+00	-0.727617188908E+00	10
	-0.100783082547E+00	-0.100783082547E+00	12
	-0.828400271629E+00	-0.828400271282E+00	(9)
1	-0.195026502900E-10	-0.195026119968E-10	6
	-0.108977937382E+00	-0.108977937382E+00	12
	-0.297762915183E-03	-0.297762915182E-03	11
	-0.109275700317E+00	-0.109275700316E+00	(12)
3	-0.156877691415E-13	-0.156877275463E-13	6
	-0.929706567589E-04	-0.929706567589E-04	12
	-0.178615479063E-14	-0.178615479062E-14	11
	-0.929706567764E-04	-0.929706567763E-04	(12)
4	-0.510756099637E-15	-0.510754690141E-15	6
	-0.305268495603E-05	-0.305268495603E-05	12
	-0.325695275035E-20	-0.325695275034E-20	11
	-0.305268495654E-05	-0.305268495654E-05	(12)
5	-0.169539795300E-16	-0.169539315585E-16	6
	-0.101867023194E-06	-0.101867023193E-06	11
	-0.556704727266E-26	-0.556704727265E-26	11
	-0.101867023211E-06	-0.101867023210E-06	(11)
6	-0.568280695828E-18	-0.568279060849E-18	6
	-0.342680025760E-08	-0.342680025760E-08	12
	-0.905673816120E-32	-0.905673816120E-32	12
	-0.342680025817E-08	-0.342680025816E-08	(11)

3.17 Angular distribution of highly charged ions transmitted through metallic microcapillaries

K. Tőkési, L. Wirtz[a)], C. Lemell[a)], and J. Burgdörfer[a)]

During the last decades studies of interactions between highly charged ions (HCI) and solid surfaces are in center of interest, which is partly stimulated by potential future technical application such as nanofabrication. So far the following picture of the HCI-surface interaction is emerged: When a highly charged ion approaches a solid surface, one or more electrons are resonantly captured at a characteristic distance (d_c) into Rydberg states of the projectile. As a result, a multiply excited Rydberg atom with inner shell vacancies, a so-called hollow atom of the first generation (HA1), is created. It is, however, usually extremely short-lived because of the image acceleration of the ion towards the surface. When the ion reaches the surface the memory of HA1 is lost and the hollow atom of the second generation (HA2) is formed. Recently, an alternative technique has been introduced to study HA1s by interaction of highly charged ions with internal surfaces of microcapillaries.

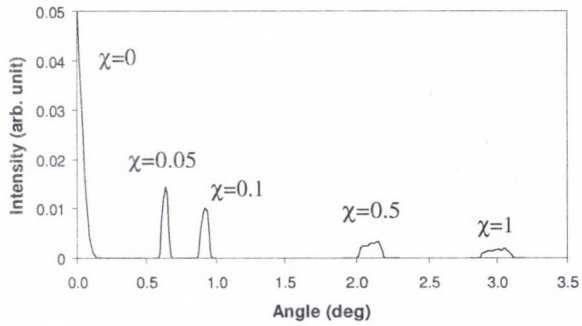

Figure 1. Angular distributions for Xe^{5+} ions for various strength of image acceleration between the ion and the Ni capillary surface at 5×10^7 a.u. distance from the capillary exit.

In this work, angular distributions of HA1s creating in microcapillary transmission as function of the interaction strength between the HCI and solid surface are studied. The interaction strength is varied from the case of insulator to the clean metal surface by variation of the surface response function $\chi = (1 - \varepsilon)/(\varepsilon + 1)$ from small values $\chi << 1$ ($\varepsilon \approx 1$) to the metallic limit ($\chi \to 1$). Here ε is the bulk dielectric response. The simulation is based on the classical over the barrier model including the neutralization and relaxation cascade. The electronic dynamics is simulated within a Monte-Carlo approach

We performed theoretical model calculations for the angular distribution of Xe^{6+} ions with an energy of 800 eV/q transmitted through Ni microcapillaries. We have shown that the angular distributions of transmitted ions can be used to identify different phases of hollow ion formation for clean metal surfaces. We have also investigated the case of surfaces which are partly or entirely contaminated by layers of insulating materials by the reduction of image acceleration. We have found that while the final charge state distributions hardly depend on the strength of the image acceleration the angular distributions change dramatically. Decreasing the image acceleration the angular distribution shifts to the lower scattering angles. Completely neglecting the image acceleration, the angular distribution is centered at zero degree.

Acknowledgements

The work was supported by the Hungarian Scientific Research Found: OTKA No. T032306, the Austrian Fonds zur Förderung der wissenschaftlichen Forschung, FWF (Austria), the grant "Bolyai" from the Hungarian Academy of Sciences, TéT A-19/2001, and EU under contract no. HPRI-CT-2001-50036.

a) Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstr. 8-10 /E-136/, A–1040 Vienna, Austria

3.18 State slective (n,l) capture distributions in low energy antiproton-helium collisions

K. Tőkési and B. Juhász

Recently the state selective capture cross sections at very low (1-100 eV) projectile energies were presented in antiproton-helium collisions [1]. The role of isotope effect was also investigated when the capture cross sections for ^{3}He and ^{4}He targets were compared. These measurements give a sensitive test of various theories when the measured cross sections are compared with the experimental data. The main difficulty in the calculations are caused by the two-center Coulomb field (created by the projectile and target) that influences the motion of the particles. The classical trajectory Monte Carlo (CTMC) method has been quite successful in dealing with capture processes in ion-atom collisions [2,3]. One of the advantages of the CTMC method is that many-body interactions are exactly taken into account during the collisions. This approximation is able to utilize various model potentials between the colliding particles in the same footing.

The state selective (n, l) cross sections for antiproton-capture as a function of impact energy are calculated for ^{3}He and ^{4}He using the CTMC technique. In the present study a three-body CTMC method [4,5] is used. The potentials representing the interactions between the components of the collision system, the case of Coulomb effective potential (Model 1) and the Garvey-type model potential [5] (Model 2) are considered.

We found the resulting (n, l) distributions of captured antiproton in good agreement with the recent measurements [1] for Model 2. For Model 1, the target potential is described by a point-like Coulomb potential. For this potential the maximum in the n distribution of the captured antiproton is shifted to the higher n values compared to Model 2. This is a strong indication of the importance of screening effect at low energy collisions.

Acknowledgements

We are grateful to D. Horváth for helpful comments and discussions. The work was supported by the Hungarian Scientific Research Found: OTKA Nos. T032306 and T033079, the grant "Bolyai" from the HungarianAcademy of Sciences and TeT-Jap-4/02.

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3.19 Photoionization cross sections of Ne(1s)

X-M. Tong[a] *and K. Tőkési*

The photoionization cross sections in the energy range between 870 and 1200 eV photon energies of Ne(1s) state are calculated by the independent particle approximation (IPA) [1,3] and by the time dependent density functional theory (TDDFT) [4,5] within the framework of linear density response theory. For the photoionization above the 1s ionization threshold, the dipole transition is dominant. As a test we include the multi-pole contributions in the calculations. We found that the contribution of multi-poles to the total cross sections is less than 0.1 %. Fig. 1 shows the total photoionization cross sections as a function of the photon energy.

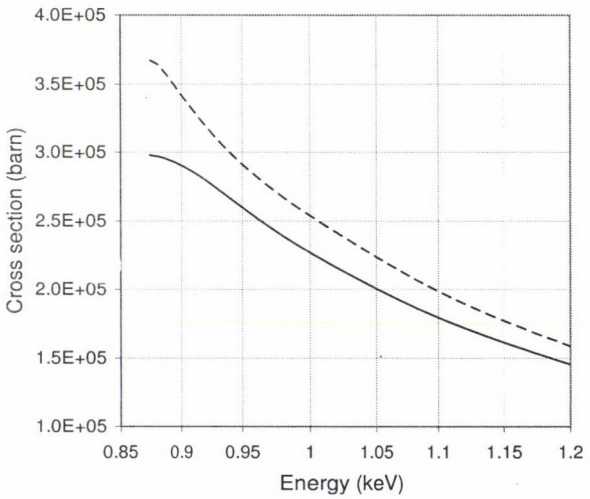

Figure 1. Photoionization cross sections: solid line: IPA, dashed line: TDDFT.

The difference between the two calculations are between 10 and 20 %, which can be attributed partly to the effect of electron correlation. The differential photoionization cross sections can be expressed by the help of total cross sections (σ_T)as:

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_T}{4\pi}\left(\Sigma_l B_1(l) P_l(\cos\theta) + \right.$$

$$\left. + B_2(l) P_l^2(\cos\theta)\cos(2\phi)\right). \quad (1)$$

The angular distribution coefficients can be calculated for given effective potentials based on either IPA or TDDFT. Keeping only the dipole transition, Eq. 1 can be simplified for linear polarized photons as

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_T}{4\pi}\left(1 - P_2(\cos\theta) + \right.$$

$$\left. + \frac{1}{2} P_2^2(\cos\theta)\cos(2\phi)\right), \quad (2)$$

and for circular polarized photons as

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_T}{4\pi}\left(1 - P_2(\cos\theta)\right), \quad (3)$$

respectively. We note that the polarization is chosen on the $x - y$ plane and the photon is propagated along the $z-$direction.

Acknowledgements

The work was supported by the Hungarian Scientific Research Found: OTKA No. T032306.

a) Physics Department, Kansas State University, Manhatten, Kansas 66506

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3.20 The role of projectile double scattering in positron-atom collisions

K. Tőkési

The process of electron capture to the continuum (ECC) can be explained as a result of the special case of ionization, where the ionized target electron is strongly influenced by the outgoing projectile. The ECC peak appears at the energy where the electron velocity is almost the same as the projectile velocity. The ECC is well understood when the projectile is heavy particle. It was shown that the most important mechanism for ECC is the Coulomb focusing of ejected target electron in the direction of the projectile and the peak occur for positron impact as well in the triple-differential cross sections [1]. Since the mass of the positron and the electron is the same, the projectile energy is shared equally between the positron and electron after the ECC. Therefore the nominal value of the ECC peak in the electron/positron spectrum is $(E - E_b)/2$. Contrarily, the experimentally obtained positions of the ECC peak always appear at significantly lower/higher energies. To solve this puzzle model calculations within the frame work of classical trajectory Monte Carlo (CTMC) method are performed.

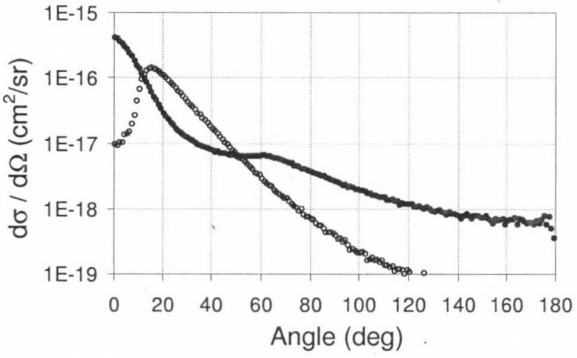

Figure 1. Angular distributions of scattered positrons at 50 eV impact energy. full circle: full 3-body approximation, open circle: neglecting the scattering on the target nucleus.

The CTMC method has been successful in dealing with the ionization process in atomic collisions for light projectile impact. In this work, the role of projectile double scattering in positron-hydrogen atom collisions is investigated. Fig. 1 shows the angular distributions of scattered positrons, and for the case of ionization channel at 50 eV impact energy. For the case of the full 3-body approximation, the enhancement in the distribution between the scattering 60^o and 80^o is due to the ionization through double scattering [2].

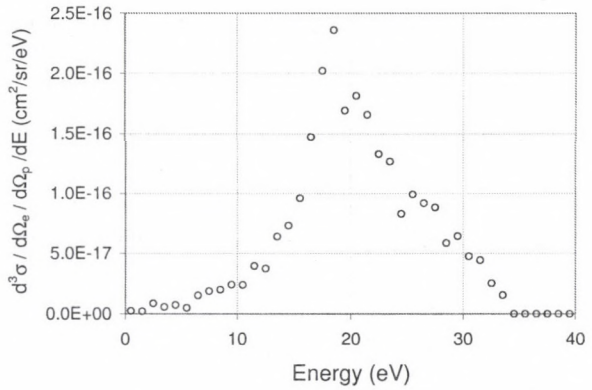

Figure 2. Energy distribution of scattered positrons at 50 eV impact energy. The scattering on the target nucleus is neglected.

Fig. 2 shows the energy distribution of scattered positrons at 50 eV primary energy when the scattering on the target nucleus is neglected. The ECC peak position is at E=18.2 eV, which is the nominal value at this impact energy. In conclusion we can say that the role of double scattering manifests itself in the energy shift of ECC peak [2].

Acknowledgements

The work was supported by the Hungarian Scientific Research Found: OTKA No. T032306, the grant "Bolyai" from the Hungarian Academy of Sciences.

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3.21 Model calculations for positron-helium scattering

L. Lugosi, I.F. Barna[a)] *and K. Tőkési*

The comparison between the results of theoretical and experimental investigations of positron–atom scattering provide valuable tests of both the quality of the applied models and wave funtions used in the calculations as well as the accuracy of the measured data. Due to the complex nature of the many-body, multichannel collision processes, very detalied theoretical studies of positron scattering by atoms have been made only for H and He (see the recently developed close–coupling calculations of Campbell et al. [1]). On the experimental side, the e^+-H system can be studied with great difficulties. In contrast, accurate experimental data have been obtained for He [2,3]. In the case of the e^+-He scattering, there are four particles and consequently six inter-particle coordinates. The wave functions of the target are not known exactly. These factors complicate the calculation procedures in comparison with those for e^+-H scattering. In order to decrease the complexity of the computational methods, reasonably accurate equivalent one–electron and complex optical model potentials based on optical theory have been proposed for a variety of scattering processes [4,5].

In the present work we consider the elastic and inelastic scattering of positron from He at energies above the 2^1S first excitation threshold at 20.61 eV, i. e. above the Ore gap energy region using a complex optical potential model (COPM) and a classical trajectory Monte Carlo (CTMC) method based on the Garvey–type model potential [6]. It is well known that the optical potential, which replaces the many–channel problem and hence can be used to study the elastic and inelastic scattering mechanism between composit systems, is defined by the Feshbach projection of the Schrödinger equation on a subset from a complete Hilbert–space basis set. The optical potential $V_{\rm opt}$ consists of three terms

$$V_{\rm opt}(r,E) = V_{\rm stat}(r) + V_{\rm pol}(r,E) + \\ +{\rm i}V_{\rm abs}(r,E), \qquad (1)$$

where $V_{\rm stat}$ is the mean static field potential term (MSF) which represents the interaction of the positron projectile with the unperturbed He atom, $V_{\rm pol}$ and $V_{\rm abs}$ are respectively the polarisation and absorption model potential which can be expressed as a function of the projectile energy E. In Eq. (1) r is the position vector of the positron with respect to the nucleus. $V_{\rm pol}$ has been expanded up to quadrupole order and the precision calculations of Bhatia and Drachman [7] were used for the polarisability coefficients. For the $V_{\rm abs}$ potential term we have adopted the expression obtained by Gianturco and Melissa [5]. In our investigations, the MSF potential was derived using three type of wave functions: Hylleraas (H), Hartree–Fock (HF) and one that was constructed from the configuration interaction approximation (CI). The objective is an approximate representation of the ground state of He in order to find out which model is capable of giving accurate data for the elastic scattering cross sections. Since, the non-Hermitian optical potential in Eq. (1) has complex radially symmetric form and short ranged, the partial wave decomposition of the total scattering wave function still makes sense. So, the elastic scattering is described by the regular solution of the

$$\left[\frac{{\rm d}^2}{{\rm d}r^2} - \frac{l(l+1)}{r^2} - \right. \\ \left. -2V_{\rm opt}(r,E) + k^2\right] F_l(k,r) = 0, \qquad (2)$$

radial Schrödinger equation, but the l-th radial wave function $F_l(k,r)$ is complex. For neutral target systems this regular solution vanishes at the origin and has the following asymptotic behaviour

$$F_l(k, r \to 0) \to 0, \quad F_l(k, r \to \infty) \to \\ \to \sin\left(kr - \frac{l\pi}{2} + \delta_l(k)\right). \qquad (3)$$

Separating the l-th partial complex phase shift $\delta_l(k)$ into its real and imaginary terms, one can write

$$\delta_l(k) = \lambda_l(k) + \mathrm{i}\mu_l(k). \qquad (4)$$

The imaginary component of the phase shift corresponds to absorption, i. e. the loss of particle flux from the incident channel. The total elastic cross section is given according to (for example, Bransden [8])

$$\sigma_{\mathrm{elas}} = \frac{2\pi}{k^2} \sum_{l=0}^{\infty} (2l+1) \Big[\mathrm{ch}\{\mu_l(k)\} - \\ - \cos\{2\lambda_l(k)\} \Big] \exp\{-2\mu_l(k)\}. \qquad (5)$$

For the numerical solution of the differential equation (2) the modified version of the computer program [9] was used.

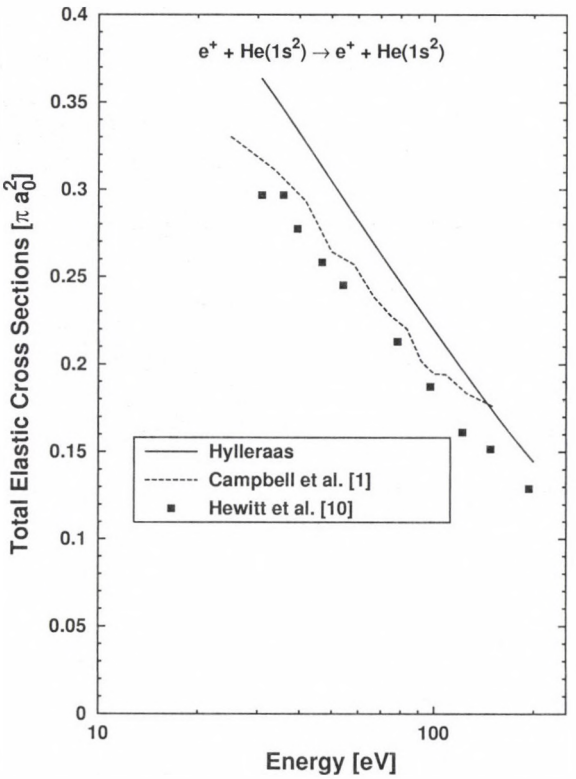

Figure 1. *Elastic integral cross sections for e^+-He scattering.*

Figure 1 shows a comparison of calculated elastic cross sections as a function of the positron energy with the previous results obtained by Campbell et al. [1] and Hewitt et al. [10]. We found that the computed cross section is sensitive to the wave function chosen for the approximate description of the ground state of He atom. The obtained values of the COPM-H and COPM-HF cross sections are in a reasonable agreement with the results of the previous quantum mechanical calculations, while the CTMC data overestimates these by a factor of 5. Improvement of the CTMC calculations is planned in the future. The relatively better agreement between the COPM-CI and the multi-state close-coupling data shows that COPM-CI model gives a good account of the elastic scattering process.

Acknowledgements

This work was supported by the Hungarian Scientific Research Found: OTKA Nos.T031833, T032306, the Grant "Bolyai" from the Hungarian Academy of Sciences, TéT A-19/2001, the Austrian Fonds zur Förderung der wissenschaftlichen Forschung, FWF (Austria), and EU under contract No. HPRI-CT-2001-50036.

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4.1 Characterization of gold plated jewellery by nuclear analytical techniques

M. Fayez-Hassan[a], *A. Simon, S. Szegedi*[b], *Á.Z. Kiss*

Egypt has a long tradition in handmade oriental crafts. It is one of the three major jewellery producers in the Middle East using more than 100 tonnes of gold a year. The Egyptian gold jewellery market ranks amongst the top ten worldwide [1]. Staple items are usually 21 carats and hand-made, however, there is also a significant mass production of jewellery, made by gold plating.

Two basic types of electroplating are used in industries: (a) Brush (or selective) plating, where metal is deposited from a water based plating solution onto a metal part, creating an electrochemical bond. The plating contact is made by brushing or swabbing the part. (b) Tank plating, which is like taking a bath in a tub and leaving the chemicals in the tub for the next sample. For quality reasons, additional agitation, filtration and laboratory analysis of the chemistry in the tanks are very important.

It is known that plating defects are unavoidable in most noble metal plating processes. Our motivation was to make a feasibility measurement of how nuclear techniques can be applied for the characterisation of quality of the gold plating. Our primary intention was to use those nuclear techniques, which are also available in the Atomic Energy Authority, Nuclear Research Centre, Egypt, for later studies; on the other hand to apply complementary techniques, if they are required.

The applied analytical methods are Neutron Activation Analysis (NAA), X-Ray fluorescence (XRF) and Rutherford-backscattering Spectrometry (RBS). Chemical composition, thickness homogeneity and Au lateral distribution of the gold contact finishing were investigated. Both NAA and XRF were carried out at the Department of Experimental Physics of the University of Debrecen. The NAA gave the major element concentrations as follows: Ni (41.4 %), Cu (24.7 %), Sn (18 %) and Au (9.1 %). Other little traces of Zn, Fe, Sb, Al, Co and O were also detected.

The XRF analyses confirmed the results of the NAA studies, but could not give further information. Therefore the thickness of the Au film, its homogeneity and uniformity needed to be measured with a high lateral resolution and depth sensitivity, too. Micro-RBS technique at the scanning nuclear microprobe facility of ATOMKI using a focussed 2 MeV He^+ ion beam was applied for this reason.

The results of the micro-RBS analyses confirmed the main elemental constituents measured by the other techniques. The calculated layer thickness of the gold was 47.50 nm in average, however the shape of the spectra unambiguously showed, that the surface was uneven. From the Au elemental maps generated by scanning the beam in areas of 200x200 μm^2 it was demonstrated that the thickness of the plated gold layer is not uniform indeed. It was also shown, that it is caused by small Cu grains on the surface. As these plating defects can create corroded pore sites on the electrical contact surface, they cause deterioration in its quality. Such an effect could be important also in case of gold contacts of microelectronic devices, which are also made by electroplating.

This work was supported partly by the International Atomic Energy Agency through the Egyptian and Hungarian collaboration No. EGY/00053R.

a) Atomic Energy Authority, Nuclear Research Centre, Exp. Nucl. Phys. Dept., P.O. Box 13759, Inshas, Egypt

b) Institute of Experimental Physics, Debrecen University, H-4001 Debrecen, P.O.Box 105, Hungary

[1] http://info.goldavenue.com/

4.2 Laser-induced optical changes in amorphous multilayers

A. Csik, M. Malyovanik[a)], S. Ivan[a)], G.A. Langer[b)], D.L. Beke[b)], S. Kokenyesi[a)], M. Kis-Varga

Technologies of nano-scale atomic engineering provide new possibilities in tailoring of properties of pure crystalline semiconductor materials (Si, Ge, GaAs), amorphous hydrogenated silicon (a-Si:H) or chalcogenide glasses as well [1,2]. The structure, optical and electrical characteristics of amorphous Si and Ge layers are widely studied [3]. Our previous investigations on laser-induced structural transformations of amorphous Si/Ge multilayers resulted an interesting results [4]. It was shown that these multilayers were stable against of crystallisation, but undergo other structural transformations under high power laser irradiation ($\alpha = 0.63\mu$m, P=1-100 W/cm^2) at room temperature which can be attributed to the local heating. Furthermore, from a comparison with the behaviour of amorphous Se/As_2S_3 multilayers, it was concluded that - in contrast to the Si/Ge system - in this case the photo-stimulated interdiffusion (without direct heating) played an important role in the change of the optical properties.

The aim of this work was to extend our preliminary results on a-Se/As_2S_3 and a-Si/Ge system [4], and to determine the characteristics and mechanism of the light-or heat-induced structural changes and interdiffusion as well as their interrelation with the optical parameters.

During experiments the blueshift of the optical absorption edge was observed in all as-deposited multilayers, which can be connected with quantum-confinement effects. In the analysis of optical transmission data the "effective optical medium" model [5] has been applied. In accordance with this model, with decreasing thickness of the well layers further shift of absorption edge and bleaching of multilayers was observed. After annealing of Si/Ge and chalcogenide multilayers the further blueshift was observed due to the thermal or laser-induced intermixing of adjacent layers. At the same time, the optical reflection coefficient of our effective optical medium decreases, because the resulted mixture has smaller density and reflection index. Two components of the induced intermixing process in chalcogenide multilayers were distinguished and attributed to the local heating and photo-effects in $As_6Se_{94}/Se_{80}Te_{20}$ multilayers, but only the thermal effects were identified for Si/Ge samples. This latter behaviour is universal for all multilayers where solid solutions may be created. Structural transformations based on the enhanced interdiffusion in these nanostructures provides the capability of spatially patterning optoelectronic devices, optical information recording. The measured 10-20% changes of optical transmission in investigated AMLs are accompanied by the corresponding changes of optical reflection coefficient R_{op} ($\Delta R_{op}/R_{op} \sim 20\%$), refraction index and even of the total thickness of AML up to 1-3%. All these can be used for optical data recording, creation of phase modulation structures, surface reliefs by localized laser irradiation.

a) Uzhgorod National University, Uzhgorod, Ukraine

b) Department of Solid State Physics, University of Debrecen, Hungary

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4.3 Electron energy loss spectra of Ge

Z. Berényi, K. Tőkési, J. Tóth, and J. Burgdörfer[a)]

Separation of surface from bulk effects is an issue of central importance of surface science. Although, numerous approaches appeared in the past defining the surface and its properties, there are still a lot of open questions to be solved. Still it is a basic and fundamental question, what we can identify as surface? One of the first intuitive treatments is given by the so called specular reflection model (SRM) [1]. In SRM the dielectric response is described by the bulk dielectric function (ε_b) below the surface and above the surface it is assumed that ε is given by its vacuum value 1. In this model, the induced potential is determined by the external charge, its image and a fictitious surface charge fixed by the boundary conditions according to the classical electrodynamics. In this assumption the presence of the surface causes the translational symmetry breaking at the interface. Later the so called three-layer model was introduced [2], where the solid and the vacuum interface is built up from vacuum, surface, and bulk layers, each having its own dielectric function. All these apply, in particular, to the electron scattering at surfaces. Reflected electron energy loss spectra (REELS) can be imagined as the weighted sum of the energy loss of electrons in the surface and the bulk. The weighting factor can be associated with the path length of the electron in the bulk and in the surface region. Evidently the direct comparison between experimental and theoretical loss functions can give us useful information about the probabilities of bulk and surface excitations.

In this work the surface and bulk excitations of polycrystalline Ge are studied both experimentally and theoretically. The loss functions derived from reflected electron energy loss spectra are compared to specular reflection calculations. Fig.1 shows the probabilities of surface and bulk excitations normalized to the number of elastically scattered electrons as a function of primary electron energy.

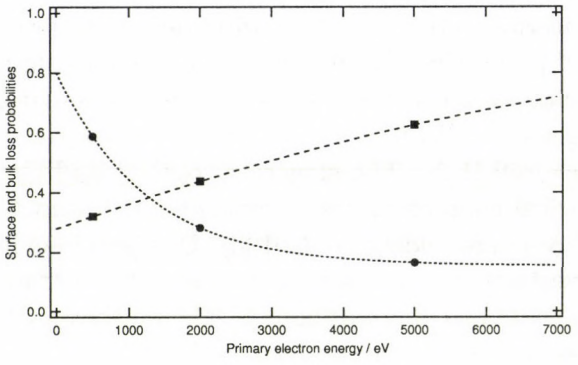

Figure 1. Probabilities of surface and bulk excitations normalized to the number of elastically scattered electrons as a function of primary electron energy. circle: surface excitation, square: bulk excitation.

In agreement with expectations, the relative contribution of the surface loss decreases with increasing primary energy. Following the hypothesis of the three-layer model, our results allow speculations for extracting information on the thickness of surface.

Acknowledgements

The work was supported by the Hungarian Scientific Research Foundation: OTKA Nos. T032306 and T038016, the Austrian Fonds zur Förderung der wissenschaftlichen Forschung, FWF (Austria), the grant "Bolyai" from the Hungarian Academy of Sciences, TéT A-19/2001, and EU under contract no. HPRI-CT-2001-50036.

a) Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstr. 8-10 /E-136/, A–1040 Vienna, Austria

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4.4 Comparison of surface composition determined by XPS and EPES

J. Tóth and Z. Berényi

In the case of optoelectronic materials and polymers the precise knowledge of the surface atomic concentration ratios is crucial from scientific and technological points of view.

The present work is a methodical study on quantitative analysis by the combination of XPS and EPES for two component inorganic compounds and polymers.

The atomic concentrations were determined by conventional Al K excitation XPS in a home made instrument [1] using the multiline approach [2] and in the same instrument by the REELS-EPES method [3], [4] using the elastic scattering cross sections of electrons [5] in the medium energy range of 1 to 5 keV. In the EPES the recoil effect (electron RBS) [6], [7], [8], [9], [10], [11] was used for the separation of the contributions originating from the elements creating the molecules of the studied materials.

EPES is an 'experimental' method for determination of electron IMFP as a function of kinetic energy of quasy-elastically scattered electrons. The experimental optimalization of the energy resolution of the instrument [12] is necessary to reveal the fine structure of the quasy-elastic peak [9] of the REELS spectra in the energy range of 0.2 to 5 keV.

Note: XPS: x-ray photoelectron spectroscopy; EPES: elastic peak electron spectroscopy; RBS: Rutherford back-scattering; IMFP: inelastic mean free path; REELS: reflection electron energy loss spectroscopy.

Acknowledgement: The authors are indebted for the financial support to the Hungarian Science Foundation (OTKA T038016).

DEDICATION: the paper was presented at the IMFP-2002 Workshop (4 - 5 July, 2002., Prague), where Dr. György Gergely, the father of EPES method [3], [4] scientific consultant of the Research Institute for Technical Physics and Materials Science of the Hungarian Academy of Sciences (Budapest) in the occasion of his 80th year birthday was awarded the Ionnes Marcus Marci Spectroscopic Society Medal.

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4.5 TDDFT and Classical Dynamics for Investigation of Intense and Ultrashort-Pulse Lasers Interaction with Surfaces

A. Orbán, C. Lemell[a] and J. Burgdörfer[a]

Progress in laser technology during the past few years has made it possible to generate ultrashort laser pulses at high intensities and optical wavelengths ($\lambda \approx 800$ nm). In some cases the laser period has become comparable with the full width at half maximum τ of the temporal intensity profile [1]. In this regime many processes become sensitive on the carrier-envelope or "absolute" phase φ. The reproducible preparation of such laser pulses is essential e.g. in attosecond inner-shell spectroscopy or generation of coherent X-ray radiation for biological microscopy. Although the phase of the laser can be fairly precisely controlled, the determination of its value has failed so far. Photoionization of atoms in strong fields is a promising process for the determination of φ [2,3], but detectable phase effects could only be observed for circularly-polarized light. Another candidate to determine φ could be photoemission from metals. Up to now there exist two studies on photoemission from metal (jellium) surfaces. One of them is based on quasi-static ionization rates [4]. Although a considerable dependence on the absolute phase was found using this model, its validity is restricted to the high intensity regime ($I \geq 10^{14}$ W/cm^2), where other (destructive) processes become increasingly important. This reduces its attractivity considerably from an experimental point of view. The other study uses time-dependent density functional theory (TDDFT) to describe photoemission [5]. This calculation supports the previous description at high intensities. Surprisingly, a strong phase dependence of the photocurrent is found already at moderate intensities (I$\approx 10^{12}$ W/cm^2).

In order to better understand the results of the quantum mechanical calculations we combined it with a semiclassical simulation of electron motion in a strong external laser field. The model used for the determination of the photocurrent is a classical-trajectory Monte Carlo method in 1D with including tunneling of electrons through the surface barrier. This method has been used for the determination of the photoionization rates of the H atom giving fairly accurate results [6]. The time dependent potential determining the motion of the electrons escaping from the surface was calculated using TDDFT. All calculations presented here were performed for a metal in jellium approximation with a Wigner-Seitz radius (radius of the sphere a metal electron occupies on the average) of $r_s = 3$ a.u. The applied external potential described a laser pulse with a peak intensity of $I = 1.57 \times 10^{13}$ W/cm^2 (E_0=0.02 a.u.) and 4 fs duration (Gaussian envelope). Its wavelenghts was $\lambda = 790$ nm.

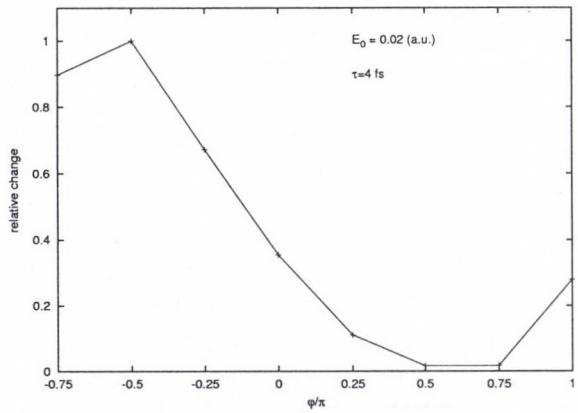

Figure 1. Relative change of the photocurrent as a function of the absolute phase φ.

Our semiclassical model also shows a phase dependence of the photocurrent. The relative change, however, is much stronger compared to the predictions of the quantum mechanical calculations. This overestimation of the phase effect can be most likely explained by the way the emission process is included in our model. The surface density of states (SDOS) is replaced by a δ-function at the Fermi energy of the jellium. Even small excitations of the electrons to the empty states of the conduction band thereby increasing the tunneling probability are so far not included. In such a

model emission crucially depends on the maximum field strength (i.e. the absolute phase) reached.

To study the dependence of the photocurrent on the laser intensity we increased the pulse duration to 10 fs (phase dependence disappears for pulse $\tau \geq 10$ fs). The maximum field strength was varied between $I \approx 0.5 \times 10^{12} - 10^{14}$ W/cm^2 ($E_0 = 0.004 - 0.05$ a.u.).

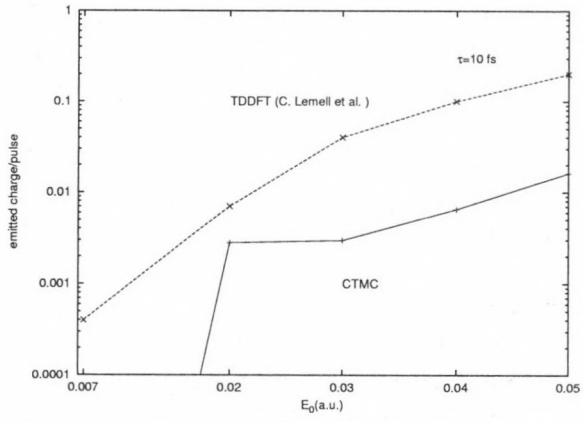

Figure 2. Total amount of charge emitted per pulse as a function of the maximum field strength.

The other parameters of the laser were the same as in the case of the phase dependence calculations. We find that the total emission in the strong field regime ($E_0 \geq 0.02$ a.u.) is by an order of magnitude smaller than predicted by TDDFT. In the multi-photon regime the photoemission is, as expected, largely suppressed by the increased width of the potential barrier.

The next step in the development of our simulation will be aimed at a more accurate description of the SDOS by also Monte-Carlo averaging the initial conditions of the electron trajectories over the complete energy range of the occupied states of the jellium in ground state. Furthermore we plan to include excitation processes on a phenomenological level by simulating the motion of the electron due to the (screened) external potential also inside the surface.

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4.6 Friction force for charged particles at large distances from metal surfaces

K. Tőkési, X-M. Tong[a], *C. Lemell*[b] *and J. Burgdörfer*[b]

When a charged particle (ion) travels along the surface, the electrons in the surface and the bulk will be polarized and build up induced charge density. This induced charge density can be visualized as image charge. The image charge is located inside the solid at the same distance from the surface as the ion but with opposite sign. Therefore, the interaction between the charged particle and its image charge is attractive and the particle will accelerate towards to surface. When the charged particle is moving with finite velocity $\vec{v}$, the induced charge density will lag behind the ion leading to an additional force in the direction opposite to that of the ion velocity. This force is the so-called friction force (stopping power) which is responsible for the energy loss of the charged particle.

During the last 80 years continuous interest manifest for studies of stopping power of atoms, molecules and solids by numerous projectiles. The works have been inspired because the accurate knowledge of the interaction between charged particle and matter has considerable importance in many different areas of research and technology such as, for example, surface diagnostics and spectroscopy. Various classical and quantum mechanical theories have been applied in the calculations, where the surface is treated either within the frame work of the local-dielectric, or the hydrodynamic, or the specular reflection model. A self consistent calculation by time dependent density functional theory (TDDFT) of the stopping power of bulk and recently of jellium surfaces is also applied which ensure a new sophisticated model of the problem.

Our recent work was highly motivated in consequence of experiments with the combination of microcapillary target and highly charged ions (HCIs). Microcapillary targets provide a new opportunities in that the surface dielectric response function can be probed in a regime where close collisions with the surface and, hence, bulk contributions can be avoided, by the investigation of the energy loss of those slow ions which do not undergo charge exchange but come close enough to the internal surface of the microcapillary to suffer a significant energy loss [1]. In order to study the energy loss of charged particles in distant collisions it is required to know the stopping power at large distances from the surfaces. In many applications of ion-surface scattering a simplified classical dielectric response picture, the so called "specular reflection model (SRM)" is very powerful tool. The key point of the SRM is that the induced charged density is highly localized on the surface, and can be characterized by the δ-shaped charge density on the interface. This assumption gives the correct representation for the long-range image potential and fails to account the realistic potential distribution in the vicinity of the surface due to the crude description of the induced charge density. The time dependent density functional theory, however provide an accurate model. We have shown that while in the vicinity of the surface the stopping power data are significantly larger calculated within the framework of TDDFT than SRM at asymptotic region from the surface the TDDFT data converge to the SRM ones.

Acknowledgements

The work was supported by the Hungarian Scientific Research Found: OTKA No. T032306, the Austrian Fonds zur Förderung der wissenschaftlichen Forschung, FWF (Austria), the grant "Bolyai" from the Hungarian Academy of Sciences, TéT A-19/2001, and EU under contract no. HPRI-CT-2001-50036.

a) Physics Department, Kansas State University, Manhatten, Kansas 66506

b) Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstr. 8-10 /E-136/, A–1040 Vienna, Austria

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5.1 Effect of CO_2 on the Sensitivity of CR-39 Etched Track Detector

I. Csige

Introduction

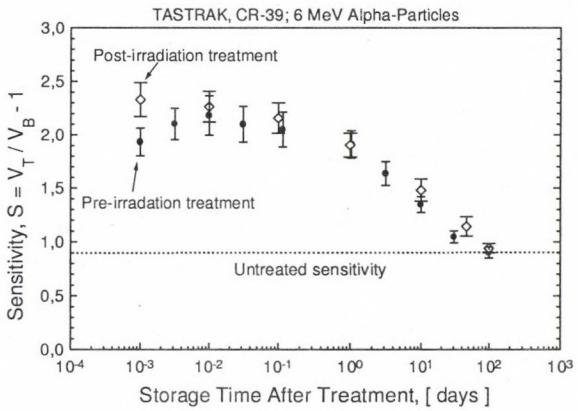
Shortly after the introduction of CR-39 as a highly sensitive etched track detector [1], it was found that its sensitivity decreases with storage time after production. Later others [2] and we [3] have shown that the sensitivity depends only on the time between production and etching but not on the time of particle incidence. It has also been observed that the original sensitivity of the material can be recovered by pre-irradiation CO_2 treatment [4]. Later we have found that not only the original sensitivity can be recovered but also it can be enhanced significantly if the CO_2 treatment is applied just before etching [5]. The treatment was found effective even if it was applied after irradiation. It is also known that during polymerization of CR-39 CO_2 gas is produced in the plastic [6]. Therefore I have concluded that the post-production decrease of the sensitivity of CR-39 is likely to be associated with the release of CO_2 from the plastic by diffusion. Resaturation of the plastic with CO_2 can recover its original (after production) sensitivity. It was expected then, however, that the recovered sensitivity of a CO_2 treated CR-39 will decrease similarly to a newly made material.

Experiment

Two sets of TASTRAK [7] type CR-39 pieces were exposed to ^{252}Cf fission fragments and alpha particles. The first (pre-irradiation treated) set of detectors was treated with CO_2 (pressure: 0.3 MPa; treatment time: 1 week) stored at room temperature in normal air for different times and irradiated 2 minutes before etching. The other (post-irradiation treated) set of detectors was irradiated, treated with CO_2, stored in normal air for different times, and etched together with the pre-irradiation treated samples. Detectors were etched in 6.25 N NaOH solution at 70 °C for 5 hours. Sensitivity for 6 MeV alpha particles was determined from the averages of minor diameters of fission fragment tracks and diameters of normal incident alpha particle tracks.

Results

The results on the figure below shows that the sensitivity of CO_2 treated CR-39 decreases as a function of time between CO_2 treatment and etching. The dependence on storage time is similar for pre- and post-irradiation treated samples, except for the first few minutes after treatment.



These results suggest that the sensitivity of CR-39 depends on the amount of CO_2 dissolved in the detector material during etching and it is independent on the time of particle incidence.

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5.2 The Hungarian LLW/ILW repository project nowadays

Zs. Szántó, É. Svingor, I. Futó, L. Palcsu, M. Molnár

The National Project on LLW/ILW repository was intended to be carried out in two phases. The first phase (1993-1996) was planned to provide the basis for the decision on the sitting of the facility. In the second phase (1997-2001) the actual realization of the facility was expected.

At the end of the first phase of the project the scientists confirmed that the Üveghuta site is potentially suitable to develop a safe repository. The continuation of the site characterisation and repository design were recommended. Preparation of an integrated safety assessment based on the available geological data was recommended to define the further needs for the geological investigations.

In the second phase detailed work on the geological and site properties forming the basis of the licensing and construction procedures commenced in the Üveghuta research area.

The second phase of the project consisted of three stages:

1. selection of a site at Üveghuta in granite massif,
2. assessment of the geological suitability of the selected site,
3. characterization of the selected site.

Preliminary safety assessments of the Üveghuta disposal facility showed that radiological doses after closure are negligibly low. In all cases examined, exposure of the population is lower by orders of magnitude than the Authority limit, which is only a fraction of the level of natural radiation.

According to the earlier exploration results, the facility could be constructed at 200 - 250 m depth in the vicinity of Bátaapáti. Its exact location could be designated only based on the results of the further exploration.

From data available from boreholes so far, disposal in tunnels seems to be the promising solution.

On completion of the first two stages of the site investigation programme the Board of National Project and the Hungarian Atomic Energy Commission made a positive statement concerning the suitability of the selected site for a geological repository in granitic host rock.

During the site characterization for disposal of LLW/ILW radioactive waste a number of steps have to be made: geological exploration, detailed study of the chosen region, understanding of site characteristics and finally its evaluation.

In this context on site surface-based work, further engineering and geological examinations were continued. The overall work will be followed by an integrated safety assessment.

In 2002 new boreholes were drilled at the site completed by geophysical and hydrogeological measurements.

The Laboratory of Environmental Studies was involved in the process of site investigation activity since the very beginning of the project. In 2002 complex isotope studies were carried out: stable isotope ratios, tritium and ^{14}C activity concentration, total beta activity of the water samples and activity concentrations of gamma emitters were measured in the region of Üveghuta and Udvari. From these environmental isotope data the residence time was calculated, the mixing conditions and origin of groundwater were determined and the direction of the groundwater flow was identified.

5.3 Development of a pre-treatment method of soil samples for radiocarbon dating

M. Molnár, Zs. Szántó, É. Svingor, I. Futó, L. Palcsu

The preparation of soil samples for radiocarbon dating represents a complex task because soil samples are often characterized by low amount (< 1 %) of organic carbon and high chemical diversity of organic components containing datable carbon.

The developed pre-treatment method solve the problem of handling high amounts of soil samples obtaining bulk carbon dioxide gas sufficient for reliable dating.

Soil samples always contain absorbed carbonates from percolating groundwater. This material gives wrong radiocarbon data due to its different formation time. Therefore carbonates have to be removed. Usually diluted HCl (10 % conc.) is used in this step. Acid is added to the sample in a beaker and the reaction is performed for 24 hours at 60°C. After this acidic treatment the sample is washed with distillate water until pH neutral and finally air-dried. The dried sample has to be pulverized before further treatment is made.

Maximum 250 g of air-dried and pulverized soil is introduced in a glass-bulb where the chemical reaction runs at 200°C and nitrogen gas purges the system continuously (Fig. 1.).

During the process (reaction time = 8 hours) reagents are added to the sample periodically. At the beginning of digestion cc. H_2SO_4 is added to the sample (approx 1ml acid to every 1g sample). After three hours the same volume of cc. H_2O_2 is added to the reaction mixture and six hours later cc. H_2SO_4 is again added in the same manner as in the first step. The reaction mixture is continuously stirred and heated during the whole process. The produced CO_2 gas mixed with the carrier nitrogen passes through a glass trap cooled at -60°C where water traces are captured, while sulphuric-oxides are trapped in a cc. H_2SO_4 trap. In the last part of the digestion system the CO_2 gas is collected as $BaCO_3$ in bubblers containing cc. $Ba(OH)_2$.

The chemically pre-treated $BaCO_3$ precipitation is further treated with H_3PO_4 (85 %), CO_2 necessary for radiocarbon dating being obtained in a controlled nitrogen stream. Gaseous impurities are removed by passing the produced CO_2 consecutively through different traps: at -60°C water is removed, at 0°C the charcoal trap catches the gas impurities and last at -196°C the cleaned CO_2 is collected.

The purified CO_2 is trapped into stainless steel vessel and measured by gas proportional counting.

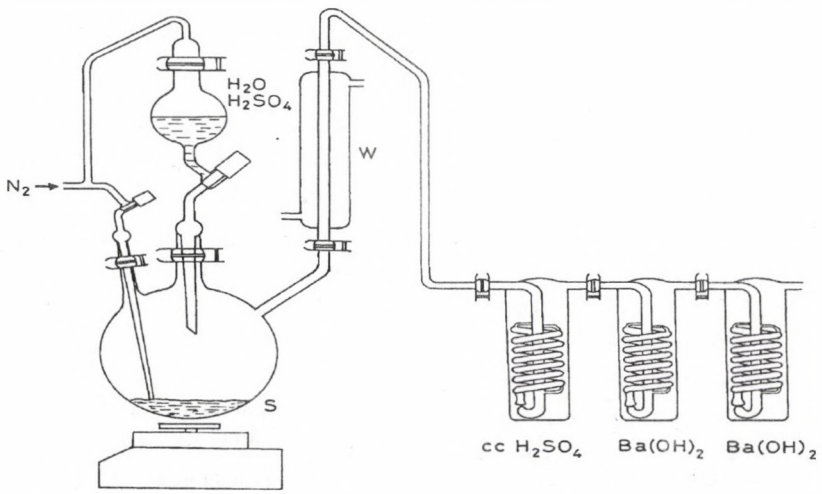


Figure 1. Digestion system for pre-treatment of soil samples

5.4 Isotopic composition of precipitation in Hungary

L. Palcsu, É. Svingor, Zs. Szántó, M. Molnár, I. Futó, Z. Major, Cs. Károssy[a)]

Tritium is one of the most commonly applied environmental isotopes in isotope hydrology. It is suitable for calculation of the age of young (< 50 years) environmental water. The aim of this work was to get a time series of the tritium content of precipitation characteristic for Hungary and to identify those factors, which have essential influence on the changes of tritium content.

We tried to find relations among these fluctuations and the actual meteorological situations [1].

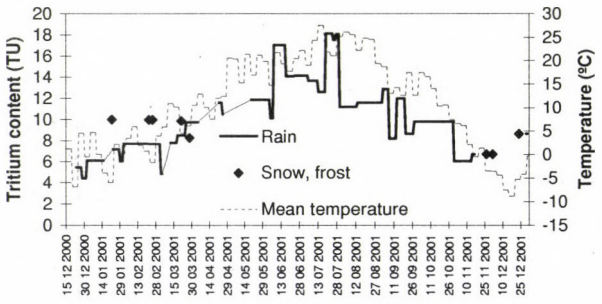


Figure 1. The tritium concentration in the precipitation and the daily temperature

The fluctuations observed in the curve in Fig 1. may be explained by the weather situations [2] and the temperature data. Comparing the tritium and stable isotope data measured in the same sample we can specify the ruling factors of the local weather situations. We can generally observe a decrease of the tritium content in case of heavy rains. Such a local minimum appears in tritium of rain between 28^{th} and 31^{st} December in 2000 when during six days it was 32 mm of precipitation. That time mostly southern (mCw, CMw), partly northern streams (mCc) dominated. The situation was similar at the end of January 2001: after a changeable period a 4-day mediterranean cyclone (CMw) determined the weather conditions and it was 14 mm of rain during three days that decreased the tritium content by 1 TU. Similar processes were responsible for the minimums observed on 25^{th} April, on 4^{th} June and on 6^{th} September in 2001. In April, a southern anticyclone causing a western stream (As) resulted a heavy rainfall (18 mm). A southern and a western anticyclone caused an abundant rainfall (45 mm) at the beginning of June. In early September, the tritium content of the precipitation decreased from 12.9 TU to 8.2 TU due to a heavy rainfall (23 mm) formed by a rather southern stream system (mCw) followed by changeable weather conditions.

There are two significant peaks in the summer period: between 6 and 16 June and between 18 and 29 July. The maximum in June is explained by the sudden heat. As a result of 7°C mean temperature increase high amount of stratospheric water vapour mixed with the cloud layers coming mostly with western streams (As) causing an increase from 10.1 TU to 17 TU in the tritium concentration of the precipitation. This is supported by the change of stable isotope ratios: both of the δD and the δ^{18}O became more positive during this warm period (δD: from -63 to -30 ‰, δ^{18}O: from -9 to -4.7 ‰. The peak of July was produced by other processes. In the second part of July the mean temperature was 27.5°C and it was little rain mostly coming from the North (mCc, CMc) and resulting an additional increase of the tritium level. The cold northern origin was confirmed by the isotope ratios: the isotope ratio of deuterium decreased from -29 to -56 ‰, the isotope ratio of oxygen lowered from -4.3 to -8.4 ‰.

In 2001 the tritium content of the precipitation varied between 4.8 and 18 TU. The monthly weighted average tritium concentration was between 6.4 and 15.6 TU. The maximum peak was observed in July and the minimum was in January. The annual mean tritium content of the precipitation was 10.4±0.3 TU.

a) Department of Natural Geography, Berzsenyi Dániel College

[1] L. Palcsu et al., J. Hydrology (submitted)

[2] Cs. Károssy et al., Savaria University Press, pp. 95-106.

5.5 Etched Track Technique to Measure ^{222}Rn and ^{220}Rn Fluxes on Soil Surface

I. Csige and I. Hunyadi

Introduction

^{222}Rn and ^{220}Rn in the human environment are considered to be a risk factor because of the radiation dose due to the inhalation of their short-lived daughters. Main source of radon is usually the soil; therefore the measurement of fluxes of ^{222}Rn and ^{220}Rn on soil surfaces is often a relevant parameter to characterise building site radon potential. The accumulation chamber method with a "real time" radon monitor is frequently used to measure spot radon fluxes. In this work we have developed an etched track detector technique to measure long-time average ^{222}Rn and ^{220}Rn fluxes.

Method

Two pieces of Radamon type etched track radon detector: one with polyethylene filter and one with paper filter can be used to measure long-time average airborne ^{222}Rn and ^{220}Rn concentrations [1]. For radon flux measurement two Radamon detectors are placed on the soil surface and are covered by a small volume cylindrical shape (length: 6 cm; diameter 10 cm) accumulation chamber. The perimeter of the accumulation chamber is pressed into the soil. The measurement time may vary from a few days to a few months. The long-time average ^{222}Rn and ^{220}Rn fluxes are calculated from the measured ^{222}Rn and ^{220}Rn concentrations using calibration factors obtained from diffusion model calculations.

Results

Model calculations were compared with measurements to study the dependence of ^{222}Rn concentration in the accumulation chamber on the depth of the perimeter of the accumulation chamber in the soil. Figure 1. shows the results.

The reliability of the method was tested in three independent experiment. In each experiment 5 accumulation chambers were used in 0.25 m^2 areas. Both ^{222}Rn and ^{220}Rn activity concentrations, measured by individual radon detectors, were within experimental error of the radon detector. Therefore, we have concluded that the method is reproducible.

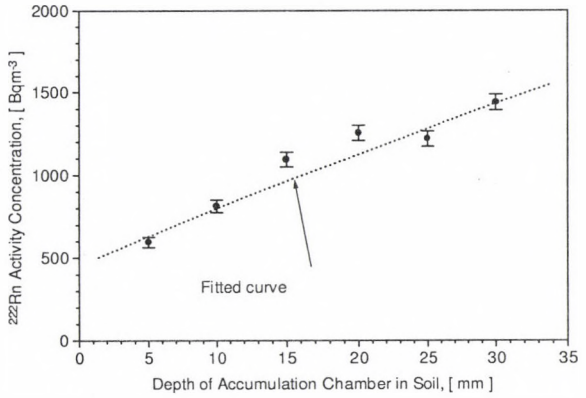


Figure 1. Dependence of ^{222}Rn activity concentration in the accumulation chamber as a function of the depth of the perimeter of the chamber. The fitted curve is based on diffusion model calculation.

The method was also compared with an independent technique to estimate the average ^{222}Rn flux on soil surface at two experimental sites. In this control method we have measured the time-average ^{222}Rn activity concentration of soil gas as a function of depth in the soil. From the depth profile we have calculated the ^{222}Rn flux assuming diffusion transport mechanism. Effective diffusion coefficient was estimated from measured soil porosity and water saturation. The ^{222}Rn fluxes estimated from depth profile and accumulation chamber technique were in agreement within the accuracy of the radon detector (approximately 20

OTKA T-029306 supported this work.

[1] I. Csige and I. Csegzi, Radiat. Meas. 34, 2001, 437.

5.6 Preliminary study of Tl and Cd uptake in the heavy metal accumulating *Brassica napus* using the Debrecen proton microprobe

Zs. Kertész[a,b], A. Haag-Kerwer[c], E. Dobos[a], G.Á. Sziki[a], I, Uzonyi[a], Á.Z. Kiss[a], B. Povh[b]

Soil contamination with heavy metals, caused by industrial activities, have grown to a serious problem in many regions of the world. Recently, novel strategies for bioremediation of heavy metal polluted soils by phyto-extraction with accumulating plants have led to a surge of interest in the physiology of accumulating plant species. Despite recent progress in understanding individual aspects of heavy metal accumulation, the cellular and whole plant mechanism is just partially known.

The high biomass producing crop plants, *Brassica juncea L.* and *Brassica napus* are very promising plant species for phytoremediation, however investigations done so far have shown that the greatest part of the heavy metal is stored in roots, and only a minor part is transported to the shoots. So the aim of further research is to help a better understanding of the transport mechanism within roots and roots to shoots of heavy metals and to find out their distribution and translocation among different cell types in the root of these species.

As the first step of this work, which is done in cooperation with the Max-Planck-Institut für Kernphysik, Heidelberg (MPI-K), and the Botanical Institute of the University of Heidelberg, we determined the distribution and concentration of major and trace elements along the roots of Cd and Tl treated as well as control plants of *Brassica napus* on the ATOMKI proton microprobe.

The heavy metal stressed and control plants were provided by the Botanical Institute of the Univ. of Hd. The frozen and freeze-dried samples were made in the cryo lab of the MPI-K. The longitudinal elemental distribution along the roots were analysed with the ATOMKI proton microprobe, using a 100 pA 5 μm x 5 μm beam of 2.5 MeV protons. PIXE spectra and elemental maps were collected in every mm along the total length of the roots.

As an example the Tl distribution in a Tl-treated young plant is presented in fig. 1.

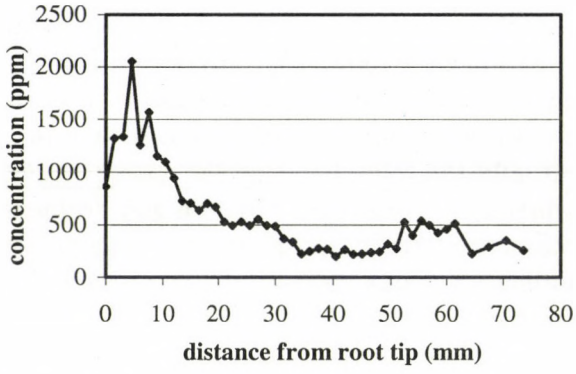


Figure 1. Tl concentration along the root of Tl-stressed *Brassica napus*

It can be seen from the figure, and also from the Cd distribution in the Cd-treated roots, that the heavy metal uptake takes place 5-15 mm from the root tip, in the root-hair zone, and than their concentration decreases or remains relatively stable, strengthening the translocation of these elements.

We have also observed that the Na, Cl and Zn concentrations are much higher (7-10 times), while the Ca concentration is about 3 times less in the Cd-stressed plants, than in the control or in the Tl-treated ones. Significant differences were found between the elemental concentrations and distributions in the roots of young and old plants. For these phenomenon no explanation exists so far.

These measurements provide new data on the longitudinal elemental distribution in the roots of the heavy-metal stressed plants, and help to select those areas within the root on which more detailed investigations should be done. Preliminary micro-beam measurements have already been performed in 10-20 μm thick (one cell size) root cross sections prepared from the root hair zone of the same plants.

a) Atomki, Debrecen, Hungary

b) Max-Planck-Institute fur Kernphysik, P. O. Box 103980, 69029 Heidelberg, Germany

c) Botanishces Institute, Univ. Heidelberg, INF 360, 69120 Heidelberg, Germany

5.7 Aerosol index, air mass trajectories and elemental characteristics during Saharan dust episodes in the Hungarian atmosphere between 1991 and 2000

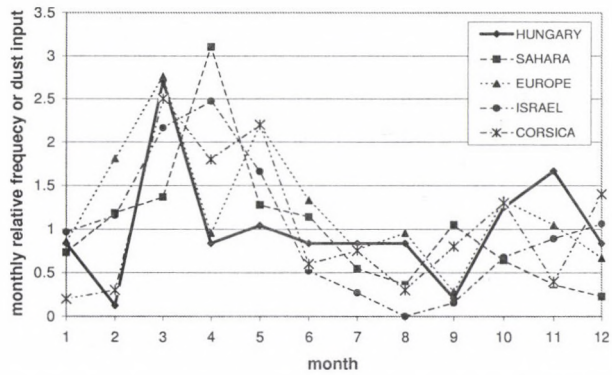
I. Borbély-Kiss, Á.Z. Kiss, E. Koltay, Gy. Szabó, L. Bozó[a)]

A considerable part of the global atmospheric aerosol burden is generated in desert dust storms. The long range transport of this component is receiving interest in many respects.

In the present work the influence of Saharan dust on the Hungarian aerosol has been investigated. Use was made of the 1991-2000 part of our data base related to Hungarian sampling sites derived with the method of proton-induced X-ray emission elemental analysis (PIXE).

For selecting Hungarian episodes to be assigned to Saharan sources three procedures have been applied. On one hand, backward air trajectories calculated in transport models were available for the periods November 1991-August 1992 and May 1995-March 1996. On the other hand, aerosol index data taken by TOMS technics on NASA satellites NIMBUS7 and EARTH PROBE and presented in global dust maps have been used in the time intervals January 1991-May 1993 and July 1996-December 2000, respectively. As an additional tool, a selection has been performed in the time series constructed for elemental concentration ratios Ti/Ca, Si/Al, Al/Ca, Ti/Fe, Si/Fe, Ca/Fe accepted in literature as regional signatures for Saharan dust. The three methods were partly used together in the same time intervals, while in other cases they were independently used for periods completing eachother. They represent different approximations. The calculated trajectories plot the transport pathes for the air masses in two or three dimensional approximation, without taking dry and wet depositions of the dust into consideration. The aerosol index represents the actual regional aerosol concentration, summed for the total mixing layer. Signature values deduced from our own data may reflect the contribution of the Saharan component near the ground level, influencing directly environmental conditions.

During the ten year period considered we assigned nearly 50 Hungarian episodes to Saharan sources. The seasonal distribution of the events here exhibits spring and autumn maxima, in agreement with earlier observations by different groups in some Saharan and Southern European/Mediterranean sites. A comparison has been made of the Italian and Hungarian observations of a long range transport episode of Saharan dust in spring 1991, remarkable similarity has been found in the results of signature evaluation for the two sites.



Some conclusions are drawn on the Saharan influence of Hungarian atmospheric aerosol from the joint evaluation with the above mentioned independent selection methods. Furthermore, the tracing properties of the regional signatures considered have been checked through the comparison of their eposodic and average values, respectively.

The contribution of NASA/GSFC TOMS group through making available TOMS images of the global distribution of aerosol index is kindly acknowledged.

Part of the work was supported by the Hungarian National Foundation for Scientific Research (OTKA No. T032264) and National Research and Development Program (NRDP 3/005/2001).

a) Institute of Atmospheric Physics, P.O.Box 39
H-1675 Budapest, Hungary

5.8 Investigation of incrusted pottery found in Hungary by μ-PIXE method

G.Á. Szíki, K.T. Biró[a)], I. Uzonyi, E. Dobos and Á.Z. Kiss

Incrusted pottery samples from the territory of Hungary were analyzed by micro-PIXE technique.

Incrustation is a specific technique used for the decoration of typically fine ornamented pottery in several periods and on several regions. The clay surface is incised to form a pattern and the colored (typically, white) substance is pressed into the resulting lines.

The aim of our study was to find regional/temporal differences in the composition of the ornaments determining the elemental composition of them.

We succeeded to group the pottery samples from different regions and periods by the composition of their ornaments. It turned out that the investigated incrusted ceramics can be divided into three groups by the composition of the incrustations. It was concluded that the elemental composition of the ornament is characteristic to the provenance of the pottery.

Samples from Vörs-Máriaasszonysziget are described by incrustations that contain a kind of grit with high calcium and phosphorus content. The grit is believed to be bone. Samples from Balatonfűzfő are described by incrustations with high calcium and carbon content. The material of the incrustation is presumably some form of mineral carbonate ($CaCO_3$.) (see fig.) The ornaments of potteries from Baradla cave (Aggtelek) have low calcium and phosphorus content and a composition that is similar to the basic material of the pottery. The main constituents of the ornaments are SiO_2, MgO, CaO and Fe_2O_3. indicating the presence of kaolin and quartz.

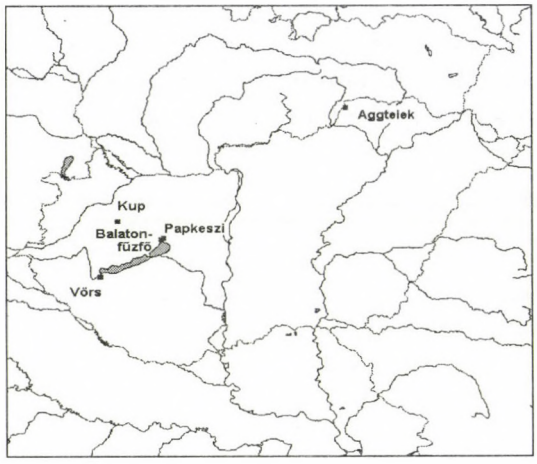


Figure 1. Provenances of pottery relics in the territory of Hungary

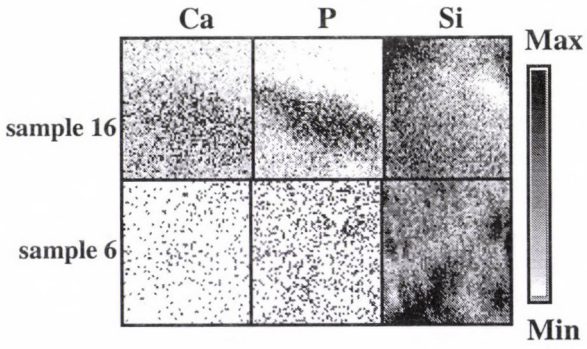


Figure 1. The elemental distributions of, calcium, phosphorus and silicon inside an incrustation of a pottery relic from Baradla cave (sample 6) and an other from Vörs (sample16).

a) Hungarian National Museum, Budapest, Hungary

6.1 Decomposition of ^{11}C-Labeled Methanol on H/ZSM-5 Zeolite Catalyst

É. Sarkadi-Pribóczki, Z. Kovács, G. Horváth[a)], *N. Kumar*[b)], *T. Salmi*[b)], *D.Yu. Murzin*[b)]

The conversion of [^{11}C]methanol has been investigated over H/ZSM-5 zeolite between 250-380 °C for the purpose of [^{11}C]methylation of benzene and toluene. The aim of this work is to obtain details about the mechanism of [^{11}C]methanol-to-[^{11}C]hydrocarbon reaction. The conversion of methanol on H/ZSM-5 had been studied by several investigators [1]. The strong Brönsted acid site of HZSM-5 zeolite can be methylated by methanol to form dimethyl ether intermediate with further conversion to light olefins and then paraffins. Compared to ^{14}C tracer technique [2], the application of "no carrier added" radiochemical method precludes the disturbing effect of natural carbon impurities starting from 11C-labeled methanol ($T_{1/2}$= 20.4 min) and at the same time it was sensitive enough to detect very low amounts of methanol or hydrocarbon products. Furthermore, compared to the use of isotopic 13C-labeling [1], this radiochemical method offers a simple way to follow the ratio of trapping of 11C-labeled methanol on the catalyst by radioactivity detectors under flow condition and to analyze the 11C-labeled products by radio-gas chromatography (gas chromatograph on-line coupled with a radioactivity detector).

The synthesis of H-ZSM-5 zeolite catalyst was carried out as described in Reference [3]. The catalyst was characterized using X-ray powder diffraction, scanning electron microscope, X-ray fluorescency and nitrogen adsorption. 250 mg H/ZSM-5 zeolite (Si/Al = 31) was filled into a glass tube (i.d. = 4 mm) and warmed up to 250 °C for two hours to remove the rest of water by He flow. The [^{11}C]methanol was produced by a classical method [4] and trapped on H/ZSM-5 zeolite by He flow at room temperature. Since the [^{11}C]methanol flow contained water trace, the column was warmed up to 130 °C for a few minutes under He flow to remove the adsorbed water and then further heated up to 250-300-380 °C while kept the column closed. The [^{11}C]products were analysed by radio-gas chromatography.

In the experiment principally only [^{11}C]methanol, [^{11}C]dimethyl ether, [^{11}C]C_3H_6 and [^{11}C]C_5H_{10} olefins were detected up to 300 °C but in the presence of benzene or toluene [^{11}C]dimethyl ether was not formed on the catalyst. The 11C-labeled products were also identified at 380 °C as a required temperature for the purpose of [^{11}C]methylation of benzene and toluene. Mainly [^{11}C]C_3H_6 furthermore [^{11}C]C_4H_8, [^{11}C]C_4H_{10}, [^{11}C]aromatics and as side products [^{11}C]CO, [^{11}C]CO_2 were detected with traces of [^{11}C]C_2H_4 and [^{11}C]CH_3OH, too.

The HZSM-5 zeolite catalyst is suitable for the conversion of [^{11}C]methanol to ^{11}C-labeled olefins through [^{11}C]dimethyl ether intermediate. The catalysis is simple and applicable not only for the production of [^{11}C]C_2H_4, [^{11}C]C_3H_6 and [^{11}C]C_4H_8 olefins but for [^{11}C]methylation of aromatic compounds, too.

This work was financially supported by The Hungarian Scientific Research Fund No. T031764

a) PET-Center, Debrecen University, H-4001, Hungary,

b) Process Chemistry Group, Łbo Akademi University, FIN-20500 Łbo/Turku, Finland

[1] O. Mikkelsen et al., Microporous and Mesoporous Materials 40 (2000) 95-113.

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[3] N. Kumar, V. Nieminen, K. Demirkan, T. Salmi, D. Yu. Murzin, E. Laine, Applied Catalysis A: General 235 (2002) 113-123.

[4] É. Sarkadi et al, Radiochimica Acta 76 (1997) 197-200.

7.1 Activities at the Van de Graaff Accelerator Laboratory

L. Bartha and E. Somorjai

During 2002 the beam time of the VdG-1 machine amounted to 92 hours. The accelerator delivered proton beam used for low energy atomic physics experiments. The beam time of the hollow cathode ion source - which is also operated on the beam transport of VdG-1 accelerator - is excluded.

The 5 MV Van de Graaff machine was operating for 1539 hours during this period. Proton (93.7 %), D^+ (5.6 %) and He^+ (0.7 %) particles were accelerated.

The beam time was distributed among different research subjects as shown in Table 1.

Table 1. Time distribution among different research activities at VdG-5

Field	**Hours**	**%**
Atomic physics	153	9.9
Nuclear physics	106	6.9
Nuclear astrophysics	107	7.0
Analytical studies	235	15.3
Analyses on the microprobe	857	55.7
Micromachining	76	4.9
Machine tests	5	0.3
Total	**1539**	**100**

7.2 Status Report on Cyclotron Operation

P. Kovács, I. Szűcs, I. Ander, T. Lakatos, A. Fenyvesi, F. Ditrói, S. Takács, F. Tárkányi

The operation of the cyclotron in 2002 was concentrated to the usual 9 months; January, July and August were reserved for maintenance and holidays. The overall working time of the accelerator was 4084 hours, the breakdown periods amounted to 15 hours last year. The cyclotron was available for users for 3620 hours, the effectively used beam-on-target time is summarized in Table 1.

Table 1. Statistics of the irradiation time (beam-on-target) for different research groups

Projects	**Hours**	%
Nuclear spectroscopy	660	36.9
Nuclear astrophysics	496	27.7
Radiation tolerance test	106	5.9
Nuclear reaction data	16	0.9
Neutron physics	23	1.3
Medical isotope production	434	24.2
Thin layer activation (TLA)	56	3.1
Total	**1791**	**100**

In order to improve the circumstances of the irradiations the following improvements were done:

- Two beam lines were rebuilt for the neutron irradiations and for thin layer activation technique
- New independent He-gas cooling unit was installed for the above mentioned beam lines
- New electronic unit was installed to follow the beam intensities as a function of the time at different target stations.
- Modernization of the RF-unit has been started
- Construction of a new large power beam sweeping unit for TLA studies

7.3 Calibration of an UTW Si(Li) detector in the 0.28-22.1 keV energy range

I. Uzonyi, Gy. Szabó, I. Borbély-Kiss and Á.Z. Kiss

Since the development of Ultra Thin Windowed (UTW) Si(Li) detectors in the early 1970s, there has been a continuously growing interest for their use both in macro- and micro-PIXE set-ups. In spite of this fact, the application of such detectors in the sub-keV region has been quite limited supposedly due to the lack of well-established calibration methods and the difficulties associated with their operation.

Until now numerous alternative experimental techniques have been elaborated to accomplish efficiency calibration. Generally radionuclide standards, photon- or ion-induced characteristic X-ray lines from selected materials, electron bremsstrahlung and synchrotron radiation are used for calibration. Despite numerous existing methods, only some of them were tested below 1 keV energy due to different problems associated with their application (e.g. lack of suitable radionuclide standards, difficulties in the preparation of thin targets for light elements, etc.).

The aim of this study has been twofold: first to check the applicability of the (micro)PIXE method for efficiency measurement of an UTW detector in the C K-Ag K_α energy region using thick targets, allowing a simple and low-cost solution for this problem; second: to test the new version of the PIXEKLM program down to the sub-keV range.

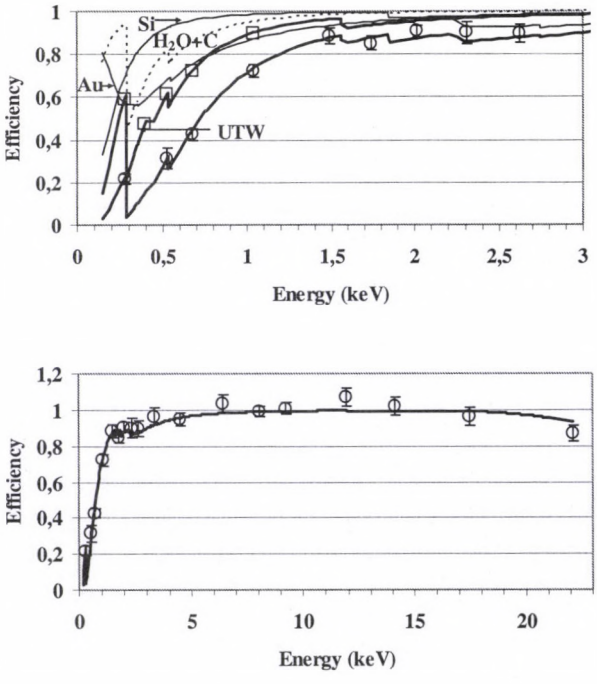
For the description of the full-energy peak efficiency of an UTW Si(Li) detector, the model of Hansen et al. [1] has been adopted. The intrinsic efficiency versus energy is expressed in the following way:

$$\varepsilon = T_w exp[-\mu_{ice}x_{ice} - \mu_c x_c - \mu_{Au}x_{Au} - \mu_{Si}x_{Si}]A$$

where T_w and the exponential factor denote the transmittance of the successive absorbing layers (UTW window, possible ice and carbon contamination on the detector surface and window, electric contact and Si dead-layer), A describes the absorption of photons in the detector sensitive volume involving the escape events, μ's are the total X-ray mass attenuation coefficients, x's are the thickness of the different layers expressed in gcm^{-2} units. Thick target characteristic X-ray yield of the k K-shell line of the element i (Y_{ik}) can be expressed as follows:

$$Y_{ik} = \varepsilon(E_{ik}) f_{ik}.$$

The f_{ik} factor can be calculated theoretically using fundamental parameters as well as experimental ones such as solid angle of the detector, collected charge, etc. From the above equation it follows that $\varepsilon(E_{ik})$ as well as the thickness of the different absorbing layers can be determined by the measurement of the Y_{ik} yields especially for the low Z-number elements. The calculated efficiency curve, experimental values, as well as the transmission factors for the UTW window, contamination layers, gold contact and Si dead layer are presented below for our detector. The accuracy of the method is estimated to be 20-10% in the 0.28-1 keV energy range and ~10-5% above 1 keV (accepted for publication in NIM B).



[1] J.S. Hansen et al., Nucl. Instr. and Meth. 106 (1973) 365.

7.4 Proton Beam Micromachining on PMMA, Foturan and CR-39 materials

I. Rajta, Sz. Szilasi, I. Gomez-Morilla[a)], M.H. Abraham[a)], and Á.Z. Kiss

Proton Beam Micromachining [1,2] was demonstrated at the Institute of Nuclear Research of the Hungarian Academy of Sciences using three different types of resists: PMMA [3], Foturan [4,5] and CR-39 type Solid State Nuclear Track Detector material [6]. These materials show refractive index change which may indicate that they can be used in microphotonics without further development. In the case of Foturan the issue of light absorption and scatter in the polycrystaline material still needs exploration. Conversely they can be chemically developed for other applications (e.g. micro electromechanical systems). The chemical development is relatively simple for CR-39 and PMMA, however Foturan requires hydrofluoric acid as a developer, which makes it a rather dangerous process. It is interesting to note that UTW PIXE was used for dose normalization, this gave us more yield than a large RBS detector would have done, because the polymer samples consist of light elements for which UTW PIXE has large sensitivity, and the RBS yield is rather low.

Irradiations have been performed on the nuclear microprobe facility at ATOMKI [7]. The proton energy was 2 MeV. Beam currents of 5-40 pA were focused down to 1-2 μm spot-size. The scan size was varied between 250-1000 μm. The required dose for PMMA, CR-39 and Foturan are 100 nC/mm^2 ($= 6.3 \times 10^{13}$ p/cm^2), 1-3 $\times 10^{14}$ p/cm^2 and 1 nC/mm^2 ($= 6.3 \times 10^{11}$ p/cm^2), respectively.

The beam scanning was done using a National Instruments (NI) card (model 6711), and the new C++ version of the program IonScan, developed specifically for PBM applications called IonScan 2.0 [8]. Each sample has been scanned over several times to eliminate the effect of possible instabilities in the beam intensity. A home made electrostatic beam blanking system was used to eliminate unwanted beam exposure.

Fig. 1. shows a detail of a structure similar to a ring resonator. The width of the gap between the straight guide and the oval is crucial for such applications. The gap is 10 pixels (9.8 μm approx.) wide, while the width of both the straight and curved lines are the same in both cases (4 pixels).

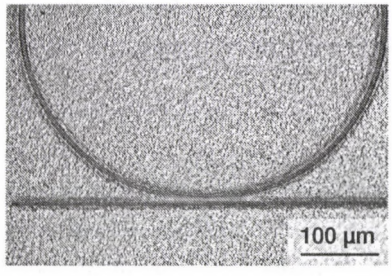


Figure 1. Ring resonator structure in PMMA

This paper has been presented at the 8th International Conference on Nuclear Microprobe Technology and Applications (ICNMTA2002) Takasaki, Japan.

This project was supported by the Hungarian National Research Foundation OTKA (Grant Nos. A080 and partly by T032264 and F42474). One of the authors (I.R.) is a Bolyai fellow.

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7.5 Carbon plasma and beam by destroying fullerene balls in the ECR ion source

S. Biri, A. Kitagawa[a)], M. Muramatsu[a)], A. Valek

Carbon beams in ECR ion sources are usually produced from gases (CO, CO_2, CH_4, C_3H_8). In all cases one always has the non-wanted mixing gas (O or H) which limits the intensity of the required C ion. To increase the carbon beam intensity is a continuously important task in the Heavy Ion Medical Accelerator (HIMAC, Chiba, Japan). In HIMAC cancer treatment is carried out by carbon beams with an energy of 290-400 MeV/u since 1994 [1]. HIMAC consists of two synchrotron rings, a linac injector, two ECR ion sources and a PIG source. The carbon ion for the cancer treatment is produced by one of the ECR ion sources daytime from Tuesday to Friday. Essentially important to increase the primary carbon beam intensity (usually C^{4+}) with high stability for long-term operations.

In last two years we developed a method in ATOMKI to produce and study normal (C_{60}) and endohedral ($N@C_{60}$) fullerene plasmas, beams and bulk materials [2]. We successfully produced high intensities of C_{60}^{Q+} ions (Q=1...5). It was logical to test C^{Q+} beams from C_{60} powder by destroying the carbon balls applying higher microwave power. We easily produced almost clean carbon plasmas and beams by the ATOMKI-ECRIS. The advantages of this new method in comparing with others are:

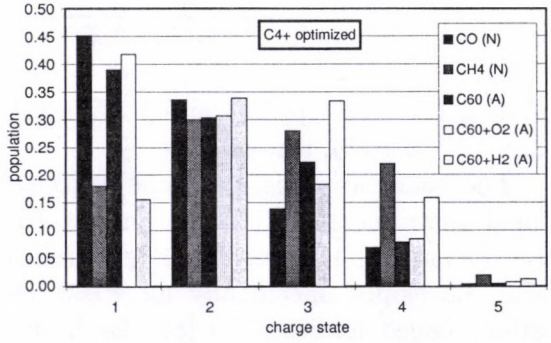
- considering the other solid carbon materials (graphite, diamond) fullerene requires a relatively low oven temperature (~500 C) to obtain carbon "gas";
- the method gives clean plasma (only C peaks are in the spectrum.);
- there are no C_n clusters for n>15 and only very few for n=2...15 were observed;
- the gas-mixing effect can be studied so a comparison with other C-contained gas methods is possible.

There are also some drawbacks: the obtained beam intensity is low yet (max. 100 μA of C^{4+}) and the consumption or loss rate of C_{60} is high and so the operation time of one load of the oven is short.

In order to make a prompt comparison we studied the gas-mixing effect by adding H and O as mixing gas to the C_{60} plasma. In both cases the ECRIS was tuned for C^{4+} production. The obtained normalized carbon peaks together with the basic case (only C_{60}) are shown in the figure. For comparison we added two typical spectra obtained in HIMAC using CO and CH_4 gases. (N: NIRS-ECRIS with CO and CH_4 gases, A: ATOMKI-ECRIS with C_{60}.). Several conclusion can be drawn.

- adding oxygen as mixing gas increases the ratio of low charges.
- adding hydrogen as mixing gas increases the intensity of the higher charges.
- the charge state distribution (CSD) of the CO spectrum (NIRS-HEC) is similar to the CSD of the C_{60}+O_2 spectrum (ATOMKI-ECRIS).
- The CSD of the CH4 spectrum (NIRS-HEC) is similar to the CSD of the C_{60}+H_2 spectrum (ATOMKI-ECRIS).

We continue these experiments in order to increase more the beam intensity of the C beams by means of improving further the C_{60} method and/or by trying a better mixing gas.



a) National Institute of Radiological Sciences (NIRS), 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan

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7.6 Optimization of the performance of a CsI(Tl) scintillator + Si pin photodiode detector for medium energy light charged particle hybride array

G. Kalinka, Z. Elekes [*,a)], *Zs. Fülöp, J. Gál, G. Hegyesi, J. Molnár, T. Motobayashi* [a)], *A. Saito* [b)] *and Y. Yanagisawa* [a)]

NaI(Tl), BGO and CsI(Tl) crystals in compact arrays will be used at RIKEN RI Beam Factory in the near future to detect gamma-rays from fast moving nuclei produced in nuclear reactions with radioactive beams, and among them CsI(Tl) for light charged particle identification as well [1].

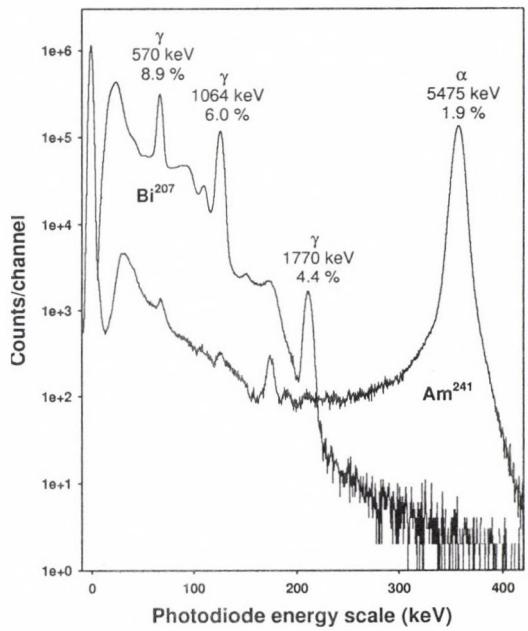
The latter system will consist of 312 Cs(Tl) crystals coupled to silicon photodiodes in a hemispherical arrangement, four detectors packed together with their own preamplifiers in each of the 78 parallelepipedic thin walled aluminum containers.

The individual CsI(Tl) crystal size is $16 \times 16 \times 55$ mm^3 in order to stop light particles with approximately 110 MeV/u. Actually one squared end is tapered in 5 mm length to fit it to 10×10 mm^2 photodiode .

The light collection efficiency and its uniformity has been optimized through measurements using numerous combinations of different surface conditions and of various wrapping materials for the sides and front face, and also by modeling with Monte Carlo calculations [2]. The best solution for our purpose is: front face polished, side surfaces specially depolished and covered with two layers of 60 μm thick 3M mirror film [3]. For the front face 3M foil or thin aluminized Mylar foils can be used, depending on the type and energy of the particles to be detected. Similar solutions in the third generation of Diamant detector system [4] in conjunction with Euroball, or in the GLAST space detector system under construction [5], also supports the excellence and justifies the choice of this 3M foil, a multilayer interference film based on giant birefringent optics [6], as a promising new alternative in scintillation detection to the presently overwhelmingly applied diffuse reflectors.

For 5.5 MeV alpha particles the light collection efficiency is $\sim$ 70%, the energy resolution is $\leq$ 2.5%, the low energy background continuum is < 3%, while for gammas the light yield is $\sim$ 30 photon/keV with $\leq$ 0.3% nonuniformity along crystal length, the energy resolution for 511 keV is < 10% (Fig. 1).

Accelerator tests for particle identification at low (20 MeV α on Carbon) and at intermediate (100 MeV deuteron on Aluminum) energies have been successfully performed at ATOMKI and RIKEN, respectively [7].



*) on leave from ATOMKI, Debrecen, Hungary

a) RIKEN, Wako, Saitama, Japan

b) Rikkyo University, Tokyo, Japan

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7.7 Peak Hold Circuit with Monolithic Transconductance Amplifier

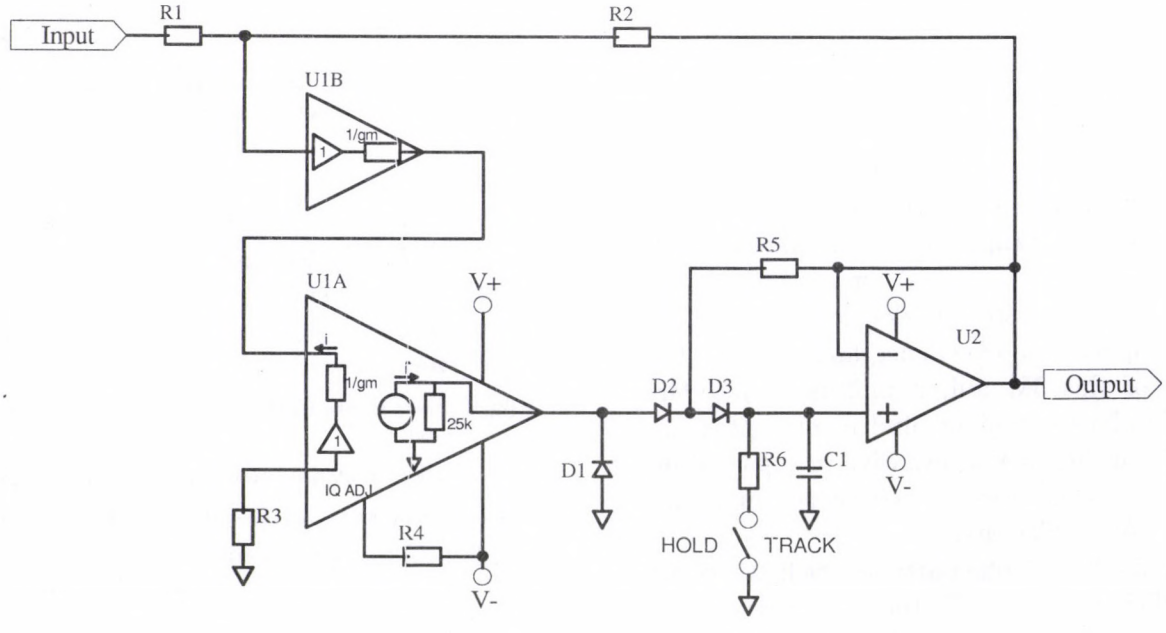
J. Gál, Gy. Hegyesi

Peak hold circuits play an important role in most high resolution spectroscopy ADC systems. They are designed to track an analogue input pulse, capture the maximum amplitude and keep that peak value on a hold capacitor. Traditional peak hold circuits use voltage amplifiers to charge the hold capacitor through a nonlinear device (e.g. diode). In order to maintain linearity, a feedback loop must encompass the diode - hold capacitor path through an output buffer. The output impedance of the voltage amplifier and the dynamic impedance of the diode make up the resistance which, together with the capacitor, determines the feedback loop pole. As the input signal approaches its maximum value, the diode's current goes to zero, increasing its dynamic impedance. That introduces a loop stability problem. The necessary compensation to stabilize the circuit, however, will make it useless in high speed applications. The peak hold circuit that we present in this report replaces the input voltage amplifier with a monolithic transconductance amplifier. A description of the circuit's operational modes follows.

During the rise time of a negative input signal, the hold capacitor (C1) is charged through two charging diodes (D2,D3), and negative feedback is applied to the amplifier through the high impedance output buffer (U2). Under this condition, the circuit works as an inverting amplifier. The rise time of the input pulses can be as short as 80 ns. The feedback circuit brakes immediately after the input goes through a maximum level and starts decaying. The circuit then enters hold mode.

In this mode, the first charging diode (D2) is reverse biased and the voltage across the hold capacitor is held equal to the maximum level. The leakage currents of the components connected to the hold capacitor cause it to discharge. The rate of this discharge is the droop rate of the circuit. A boot-strap circuit (R5, D3) in the input stage of the output buffer amplifier, minimizes the droop error which occurs during periods of long peak-hold duration.

The hold capacitor could be intentionally discharged by enabling the reset circuit (R6, HOLD/TRACK Switch) within the circuit. If the discharge rate of the hold capacitor is higher than the decay rate of the input signal, the output of the circuit will follow (track) the input even when the signal is decaying.



7.8 Algorithm for Automatic Chemical State Determination by XPS

J. Tóth

In the usage of XPS-ESCA one of the main objectives is the determination of different chemical states for a complex material from the XPS spectrum. In the case of even a few-component material or an alloy, the structure of the spectra can be very complicated. To solve the problem of the decomposition of the components, some computer manipulations should be made on the spectra using reasonable steps from quantitative analytical point of view.

1st step: the detection efficiency should be corrected by comparison of a measured spectrum on an efficiency calibration standard material in the lab to a measured international standard 'absolute' spectrum recorded on the same material.

2nd step: the energy scale should be adjusted with the help of XPS spectra for the main-component elements and chemically similar materials (chemical state matching principle) recorded by the 'same' excitation source (maybe with correction for monochromatic excitation even in the case of conventional excitation sources). Full spectra are necessary (multiline approach). Problems: 1. Overlapping photoelectron and Auger lines: Step towards the solution is: more excitation sources should be used tuning the excitation energy (multi excitation- energy approach). 2. Charging effects: to solve the problem, a combination of the XPS-XAES multiline patterns is necessary.

3rd step: to cut the questionable narrow spectra region which is necessary for the assignment of the chemical bonding states, again with the help of measured standard materials XPS spectra recorded in the same instrument using the same setup (best way), but with a more sophisticated algorithm by the use of standard spectra taken in different labs and with different instrumental set ups.

This algorithm is only suitable for homogenous materials; in the case of layered-structure materials or inhomogeneous materials the algorithm should be revised. The question is how to use standard XPS spectra to decompose the different chemical states when XPS spectra of the components were measured in different laboratories and with different instrumental set ups. Some experiences and new ideas are presented. Special peak shapes are discussed, and steps towards automatic quantitative analysis are mentioned as well. Application examples are mentioned from the field of corrosion science for special material groups.

Expert system: only in special areas of different application fields and specialized for the materials or material groups depending also on the spatial arrangement of these materials.

Acknowledgements: The author is indebted for the financial supports from IUVSTA and Hungarian National Science Foundation (OTKA: T 038016).

Note: the paper was presented at the 34th IUVSTA Workshop XPS: From Spectra to Results - Towards an Expert System, organized by the Societe Francaise du Vide, from 21-26 April 2002, in Saint Malo, France.

7.9 GEANT4 Monte Carlo simulations of sources measured with the GSI Total Absorption Spectrometer

A. Algora[a,b], *J.L. Taín*[a], *E. Nácher*[a], *B. Rubio*[a], *D. Cano-Ott*[c] *and A. Gadea*[d]

Beta decay experiments are a primary source of information for nuclear structure studies and at the same time complementary to in-beam investigations far from stability. Although both types of experiment are mainly based on γ-ray spectroscopy, they face different experimental problems. The so called *Pandemonium effect* [1] is a critical problem in β-decay if we are to test theoretically calculated transition probabilities. The solution to this experimental problem is to create a device, a Total Absorption Gamma Spectrometer (TAGS), which ideally is sensitive to the β population of the nuclear levels rather than to the individual gamma rays [2]. A TAGS can be constructed using a big scintillator crystal (4π geometry), which acts as a calorimeter for γ-ray cascades that follow the β-decay process.

The analysis of real data taken with a total absorption spectrometer requires the solution of the so-called 'inverse problem' [3]. An essential ingredient for the solution of this problem is the calculation of the response function of the spectrometer to different gamma cascades using Monte Carlo techniques. Earlier work exploited the possibilities given by GEANT3 to its limits [3], but some problems remained. From the experience obtained in [3], it was deduced that the GEANT3 code is not able to reproduce accurately the penetration of the β particles in the crystal. The correct reproduction of this effect may have an important contribution in the precise determination of the strength. The application of the new version of the Monte Carlo code, GEANT4 (version 4.3.0) , which provides an improved treatment of the low energy electromagnetic processes solves this problem. Using this code we were able to reproduce correctly radioactive sources (^{24}Na, ^{90}Y) measured with the "bare" GSI TAGS crystal ($\phi = 35cm \times l = 35cm$ NaI) using a unique density for the crystal reflector material (2.5 g/cm^3). Using GEANT3 it was only possible to reproduce both sources when different reflector densities (MgO) were used for the Monte Carlo simulation of the interactions of γ-rays and electrons with the TAS [3].

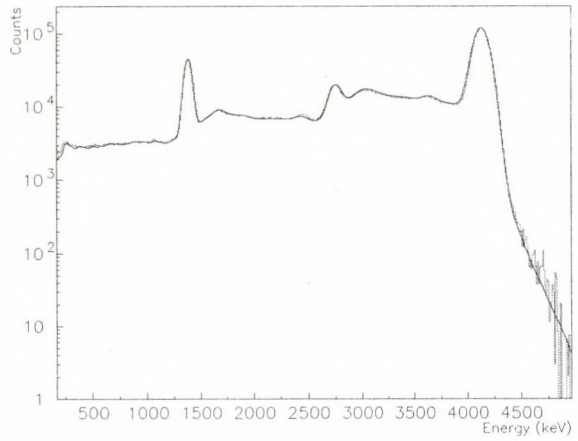


Figure 1. Comparison of the GEANT4 simulation with the ^{24}Na spectrum measured with the "bare" GSI TAS. "Bare" means that the sources were measured using the simplest possible geometry (no plug detector, no ancillary detectors were used for the measurements, only the main crystal) in order to test the physics of the Monte Carlo simulations and reduce the uncertainties related to the implementation of the geometry of the experimental setup. For details of the TAS geometry see [4].

a) IFIC, Valencia, Spain

b) MTA ATOMKI, Debrecen, Hungary

c) CIEMAT, Madrid, Spain

d) LNL, Legnaro, Italy

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41. Sulik B.: *Multiple scattering in ion-impact ionization: Fermi shuttle.* Atomic Physics Seminar at the University of Giessen. Giessen, Germany, Feb. 14, 2002.

42. Sümegi P., Szántó Zs.: *Magyarország löszszelvények izotópkémiai vizsgálata - egy alternatív paleoklimatológiai modell alapjai.* Izotópgeokémiai Ankét. FKK, Budapest, 2002. árprilis 25.

43. Tóth J.: *Felületi kémiai összetétel meghatározása XPS és REELS-EPES módszerrel.* Az MTA Felületkémiai és Nanoszerkezeti Munkabizottságának tudományos ülése. Bp., MTA KKKI, 2002. november 20.

44. Tóth J.: *XPS és REELS-EPES mint kvantitatív felületanalitikai módszerek alkalmazása a polimerek tanulmányozásában.* ELFT Anyagtudományi Szakcsoport 2002. Évi őszi Iskola. Visegrád, 2002. szeptember 23-25.

45. Tőkési K.: *Töltött részecskék kölcsönhatásai felületekkel.* MTA MFA, Budapest, 2002. április 10.

46. Tőkési K.: *Scattering of highly charged ions at metallic microcapillaries.* RIKEN, Japan, Nov. 28, 2002.

47. Trócsányi Z.: *QCD radiative corrections to γ^* γ^* -¿ hadrons.* CERN Theory Division Seminar. Geneva, Switserland, Aug. 2, 2002.

48. Trócsányi Z.: *30 éves a kvantumszíndinamika.* Ortvay kollokvium. ELTE, Budapest, 2002. április 11.

49. Trócsányi Z.: *Progress in NLO QCD calculations.* University of Torino. Torino, Italy, 31. Oct., 2002.

50. Ujvári B.: *GURU unfolding using the photon-photon interaction at OPAL.* ATLAS Seminar, München, Germany, Ludwig-Maximilians-Universitat München, LS Schaile, 24 April, 2002.

8.8 Hebdomadal Seminars

1. January 17 *Study of CPT-symmetry with slow anti protons* D. Horváth
2. January 24 *Radon in the environment* I. Csige
3. January 31 *Segregation and diffusion in nanostructures* D. Beke (University of Debrecen)
4. February 7 *Stars on the Earth - Laboratory astrophysics with X-ray microcalorimeter* E. Takács (MIT and University of Debrecen)
5. February 21 *Radon and radium content of thermal and mineral waters* E. Baradács
6. March 14 *3D proton beam micromachining* I. Rajta
7. March 19 *State of affairs* M. Pálinkás, R. Lovas
8. 28 March *The CERN/CMS Barrel-Muon Alignment project* J. Molnár
9. April 18 *Possibilities of nuclear methods in observing prohibited and dangerous materials* J. Csikai (University of Debrecen)
10. May 16 *Renormalization group: tool and meta-theory* J. Polónyi (Strasbourg/Budapest)
11. May 30 *Applications of inert gas mass spectrometry* L. Palcsu
12. June 13 *Electron beam litography on* $Bi_2Sr_2CaCu_2O_8$ *superconducting single crystal* K. Vad
13. September 10 *The fate of matter on accreting neutron stars* M. Wiescher (Notre Dame, USA)
14. September 26 *Study of thermal stability of amorphous Si/Ge multilayers* A. Csik
15. October 31 *New presentation tools in the Atomki lecture hall and the video camera as a radiation detector* A. Sipos, Z. Máté
16. November 7 *Neutron sources based on the MGC-20E cyclotron and their applications* A. Fenyvesi
17. November 20 *Microcalorimeters for X-ray spectroscopy of laboratory and astrophysical plasmas* E. Silver (Cambridge, MA, USA)
18. December 5 *Fronts, cyclones, tornados: environmental streams in laboratory* T. Tél (ELTE)
19. December 10 *Study of gas volume of low and medium activity radioactive waste storers* M. Molnár
20. December 12 *X-ray diagnostic curved crystal spectrometers* L.T. Hudson (NIST, Gaithersburg, MD)

Author index

Kiadja a
Magyar Tudományos Akadémia Atommagkutató Intézete
A kiadásért és szerkesztésért felelős
Dr. Lovas Rezső, az intézet igazgatója
Sokszorosítás:
REXPO Kft. nyomdaüzeme
4032 Debrecen, Poroszlay út 6.
Tel: 52/452-555, Fax: 52/452-666
e-mail: rexpo@rexpo.hu
Felelős vezető: Rácz János
Debrecen, 2003. július